National Marine Pollution Program

Federal Plan for Ocean Pollution Research, Development, and Monitoring

Fiscal Years 1988-1992

Prepared by the
National Ocean Pollution Program Office
For the
National Ocean Pollution Policy Board

September 1988

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of the Chief Scientist

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QUALITY

NATIONAL OCEAN POLLUTION PROGRAM OFFICE

Amor L. Lane, Director; William G. Conner, Eileen Curry, Edward J. Flynn,
Laura A. Gabanski, Ann H. Georgilas, Carolyn A. Goodfellow, Sari Kiraly,
W. Lawrence Pugh, Wendy Smith, Devorah Zeitlin

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U.S. DEPARTMENT OF COMMERCE
C. William Verity, Secretary

National Oceanic and Atmospheric Administration
William E. Evans, Under Secretary

Office of the Chief Scientist
Melvin N. A. Petersen, Chief Scientist

UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary for
Oceans and Atmosphere
Washington, D.C. 20230

DEC 30 1988

Dear Sirs:

I am pleased to submit the Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1988-1992, as required by the National Ocean Pollution Planning Act of 1978, Public Law 95-273 (as amended).

Sincerely,

William E. Evans

Enclosure

The President
President of the Senate
Speaker of the House of Representatives

ACKNOWLEDGEMENTS

Many people have taken part in the planning, drafting, and review of the Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1988 - 1992. The National Ocean Pollution Policy Board met five times during the year-long effort required to produce the Plan. The members of the Board and the Task Force to the Board assisted in determining the scope and organization of the Plan. Every department and agency represented on the Board also made available technical experts and program managers to assist in developing the informational content of the Plan. Finally, the National Ocean Pollution Policy Board contributed by reviewing early discussion papers and the final draft of the Plan to assure that both national priorities and agency interests were given proper consideration.

During the preparation of the Plan, the Board established a working group for each of the six goals of the National Program. The members of the six working groups were chosen from Federal and state agencies and appropriate nongovernmental sectors. The working group members provided information on the technical aspects of the issues and proved to be a fertile source of ideas for research recommendations. In excess of 100 people (listed in Appendix A) invested considerable time and energy into the deliberations of the working groups. The preparation of a quality Federal Plan depended to a large extent on the devotion of the working group members.

Staff members of the NOAA National Ocean Pollution Program Office served as working group leaders and directed the effort of the technical staff from Technical Resources, Inc. (TRI) in the drafting of the Plan. NOPPO and TRI staff are listed below with the sections of the Plan to which they contributed:

Introduction -- Ms. Wendy Smith (NOPPO) and Ms. Eulalie Sullivan (TRI)
National Program -- Ms. Wendy Smith (NOPPO) and Mr. George Townsend (TRI)
Toxics -- Mr. Larry Pugh (NOPPO) and Dr. Tom Duke (TRI)
Nutrients -- Mr. Larry Pugh (NOPPO) and Mr. Joe Greenblott (TRI)
Biological Agents -- Ms. Laura Gabanski (NOPPO) and Mr. Isaac Diwan (TRI)
Habitat Loss -- Ms. Laura Gabanski (NOPPO) and Mr. Drew Zacherle (TRI)
Ecosystem Status -- Ms. Sari Kiraly, Ms. Eileen Curry and Dr. William Conner (NOPPO), and Dr. Tom Duke (TRI)
Human Health -- Ms. Devorah Zeitlin and Mr. Edward Flynn (NOPPO) and Mr. Ron Brown (TRI)

Mr. Drew Zacherle also served as the project manager for TRI. Without Mr. Zacherle's patience and tireless efforts, the Federal Plan would not have been produced on schedule. Special recognition should be given to Dr. William Conner who played a major role in developing the concept and approach used for the Plan and served to coordinate the efforts of the NOPPO staff and TRI. Ms. Lizz Goodfellow and Ms. Ann Georgilas also deserve recognition for their efficient efforts to coordinate the arrangements for working group meetings and the publication of this document.

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PREFACE

The National Ocean Pollution Planning Act of 1978 (P.L. 95-273, as amended) calls for the establishment of a comprehensive, coordinated, and effective Federal program for ocean pollution research, development, and monitoring. As required by the Act, the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), in consultation with other agencies, prepares a five-year Federal Plan for Ocean Pollution Research, Development, and Monitoring every three years. This document represents the fourth edition of the Plan and covers Fiscal Years 1988-1992. This Plan establishes six goals for the National Marine Pollution Program, discusses the extent to which ongoing Federal programs are meeting these goals, and provides recommendations for improving the overall effort in marine pollution research and monitoring.

The National Ocean Pollution Program Office (NOPPO) is assigned responsibility within NOAA for updating the five-year Plan and coordinating the implementation of recommendations in the Plan. These efforts are conducted in cooperation with the National Ocean Pollution Policy Board. NOAA established the interagency Board under the authority of Section 3A of the National Ocean Pollution Planning Act. The Board is chaired by NOAA and is composed of senior representatives from eleven Federal departments and agencies.

This update of the Federal Plan for Ocean Pollution Research, Development, and Monitoring has been prepared by NOPPO with assistance and review of the agencies that participate in the National Marine Pollution Program. The Plan is submitted by NOAA to Congress with the endorsement of the departments and agencies that are represented on the National Ocean Pollution Policy Board.

Amor Lane
Director,
National Ocean Pollution
Program Office

EXECUTIVE SUMMARY

The National Marine Pollution Program is the composite of all programs funded by the Federal Government that conduct marine pollution research, development, or monitoring activities. In FY 1988, the Federal Government expended an estimated $107.2 million for marine pollution research and monitoring activities. These activities were funded by 11 Federal departments and independent agencies and included studies pertaining to pollution in coastal areas, estuaries, open oceans, and the Great Lakes. This Plan represents the fourth such document in the continuing interagency planning process called for in the National Ocean Pollution Planning Act of 1978 (P.L. 95-273), as amended. As required by the Act, a comprehensive 5-year Plan for the overall Federal effort is prepared and updated every 3 years. This Plan identifies national marine pollution needs and problems, describes the existing Federal capability for conducting marine pollution research and monitoring, analyzes the extent to which existing Federal programs assist in meeting these needs and problems, and makes recommendations for improving the National Marine Pollution Program.

To assist in identifying the areas of marine pollution research, development, and monitoring in most need of scientific information, six broad goals of the National Program have been identified. The topics covered under the six goals incorporate issues associated with each of the various polluting activities and pollutants of concern. The research and monitoring recommendations presented in this plan address the information required to meet these goals.

The Plan is presented in four chapters. These are the Introduction, which includes a discussion of the interagency planning process; a description of the National Marine Pollution Program; a discussion of the goals of the National Program; and the identified "action items" for implementation by the National Ocean Pollution Policy Board.

THE NATIONAL MARINE POLLUTION PROGRAM

Estimated expenditures for marine pollution research in FY 1988 by the 11 Federal agencies and departments that comprise the National Marine Pollution Program are shown in Table A. The U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, and Minerals Management Service of the U.S. Department of the Interior funded 70% of the marine pollution research and monitoring activities supported by the Federal Government in FY 1988.

Since FY 1984, Federal support for marine pollution research has decreased by 12% or $13.9 million ($121.1 million in FY 1984 to $107.2 million in FY 1988) (Figure A). Under the Presidential budget request for FY 1989, Federal marine pollution funding is proposed to decrease by an additional $8.3 million or 8% from current FY 1988 levels to $98.9 million. Most of this decrease reflects the Administration's efforts to eliminate unnecessary programs and programs that have already met their legislated mission.

A more detailed discussion of Federal marine pollution funding trends is presented in Chapter II of this Plan, as well as an overview of the marine pollution-related programs of each of the Federal agencies conducting marine pollution research, development, and monitoring activities.

GOALS OF THE NATIONAL PROGRAM

The six goals of the National Marine Pollution Program are discussed in Chapter III of this Plan. For the purposes of this Plan, a goal is considered to be an endpoint relating to our knowledge of the causes and implications of marine pollution that can be addressed or achieved through Federal research, development, and monitoring activities. These goals are listed below:

Goal 1: <u>Toxic Materials</u>. Understand the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities;

Goal 2: <u>Nutrients</u>. Understand the sources, fates, and effects of nutrients entering the marine environment as a result of human activities;

Goal 3: <u>Biological Agents</u>. Understand the sources, fates, and effects on marine organisms of biological agents that are introduced or influenced by human activities;

Goal 4: <u>Loss or Modification of Marine Habitats</u>. Understand the effects of losing or modifying marine habitats as a result of human activities;

Goal 5: <u>Status of Marine Ecosystems</u>. Document the trends in the status of marine ecosystems; and

Goal 6: <u>Human Health</u>. Understand the implications of marine pollution to human health.

Table A. Estimated FY 1988 Federal Funding for Marine Pollution Research, Development, and Monitoring ($ in thousands)

Agency	Estimated FY 1988 Funding
Council on Environmental Quality	9
Department of Agriculture	3,167
Department of Commerce	
National Institute of Standards and Technology	0
National Oceanic and Atmospheric Administration	25,420
Department of Defense	
Corps of Engineers	8,500
U.S. Navy	1,235
Department of Energy	5,767
Department of Health and Human Services	
National Institute of Environmental Health Sciences	486
Food and Drug Administration	2,959
Department of the Interior	
Minerals Management Service	18,000
Fish and Wildlife Service	4,735
U.S. Geological Survey	2,783
Department of Transportation	
U.S. Coast Guard	1,744
Environmental Protection Agency	31,715
National Aeronautics and Space Administration	480
National Science Foundation	151
TOTAL	107,151

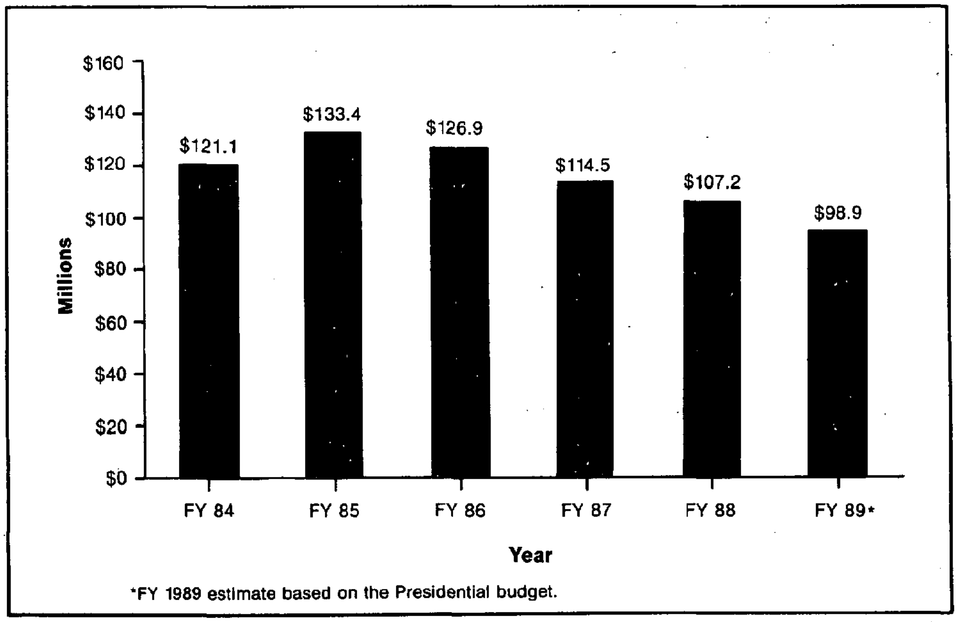

Figure A. Total Funding for the National Marine Pollution Program, FY 1984 - FY 1989.

The first four goals of the National Program address specific categories of pollutants or physical alterations to the marine environment (i.e., toxic materials, nutrients, biological agents, and habitat alterations). The last two goals (related to the status of marine ecosystems and human health) integrate the first four goals and permit the Plan to take into account all of the various contributions to marine pollution.

The marine pollution research, development, and monitoring programs funded by the Federal agencies contribute to these six areas of endeavor. To meet these goals, the scope of the programs undertaken would include the following: assessing the state of the environment (e.g., basic understanding, assessing effects, implementing monitoring systems), developing the capability to predict (e.g, impacts of human activities), and developing multipurpose program support capabilities (e.g., quality assurance, measurement methodologies).

The six goals of the National Marine Pollution Program were developed for the purpose of evaluating the effectiveness of the National Program in providing information for managing the Nation's marine pollution problems. For each goal, Chapter III of this Plan includes a discussion of the goal definition, the Federal role in addressing the goal, management questions and information needs related to the goal, and conclusions and recommendations with regard to the goal.

The recommendations presented in this Plan describe opportunities for the most useful and productive research related to each goal. However, specific program and budget decisions regarding marine pollution research, development, and monitoring activities will continue to be made in the context of the President's overall national domestic priorities and budget policies. It is ultimately up to the discretion of individual agencies to accept and implement the recommendations offered in this Plan within the context of the Presidential fiscal policies and the Federal budget processes.

The six goals of the National Program and the opportunities for Federal research, development, and monitoring activities related to each goal are presented below. Further discussion of these recommendations is presented in each goal section.

Goal 1: Toxic Materials

<u>Conclusions</u>:

- o In most coastal regions of the country, we do not know the relative contribution of atmospheric inputs and episodic events to chemical contaminant loadings in these areas.

- o There is a lack of understanding concerning the processes that control the routes, rates, and reservoirs of various chemical contaminants released into the marine environment.

- o For many toxic substances, very little is known concerning their physical chemistry and its effect on bioaccumulation.

- o Further documentation and understanding of sublethal effects of toxic chemicals is needed, especially with regard to the relationship between the effects on individuals and the integrity of populations of living marine resources.

- o There is a general lack of understanding of the interactive effects (synergism, additivity, and antagonism) for many important classes of marine pollutants.

<u>Recommendations</u>:

Sources and Loading Rates

- o Efforts to determine the level of atmospheric inputs of toxic materials to the Great Lakes should continue. Similar monitoring activities in major estuaries where atmospheric inputs are suspected to be significant would improve our understanding of this area.

- o Further research would enable the evaluation of loading rates of toxic materials associated with storm events and the importance of the timing of these events with respect to effects on biological activity.

Transport and Bioavailability

- o Research to determine the mechanisms of resuspension and deposition of sediments and associated chemical contaminants and the kinetics of sorption/desorption should be continued.

- o To be most effective, programs to evaluate toxic materials in the marine environment should include basic physical chemistry research on interactions with seawater and particulate organics. New and improved techniques for sampling and measurement of toxic materials in selected marine microenvironments (e.g., surface microlayer) would be useful. The use of partition coefficients to build models of the fate of toxic materials should be expanded.

- More information on the identity, distribution, and rates of formation of biotransformation products and how mutagenic and carcinogenic products are transformed (activated/deactivated) and accumulated by marine organisms would improve our understanding of chronic or latent effects of toxic material on marine organisms.

Effects

- Research both to develop and validate sublethal toxicity tests with more chemicals and test organisms and to develop monitoring tools to assist in recognizing the presence and levels of toxicants and possible sublethal effects would improve our ability to identify and manage problems associated with toxic materials.

- Studies to evaluate population changes should focus on defining the significance of multiple responses to toxic contamination. For example, studies to determine the relationship between contaminant concentrations in the sediment and interstitial waters and contaminant content of tissues, activity of detoxification enzymes, seasonal alterations in energy reserves, recruitment of juvenile stages, reproductive condition, and incidence of disease and histopathological conditions would provide useful information.

- It would be useful to acquire more information concerning the toxicities and sublethal effects of additional problem contaminants in order to identify their contribution to environmental stress and their mechanisms of impact. Tests should be conducted with individual and combinations of toxic substances to identify synergistic, antagonistic, or additive effects. Research should also include a determination of the influence of environmental factors, such as salinity and pH, on synergistic, antagonistic, and additive effects.

Goal 2: Nutrients

<u>Conclusions</u>:

- Although there is much information on loadings from point sources of nutrients, there is very little information on the role of groundwater and atmospheric routes of input, and on the role of runoff during episodic events.

- Although phosphorus appears to be the limiting nutrient in most freshwater systems, nutrient limitations in coastal and estuarine systems are not fully understood and may vary from place to place as well as seasonally.

- Evidence exists to suggest that excessive anthropogenic nutrient inputs have altered the trophic structure of some coastal ecosystems.

- The quantitative relationship between allochthonous (external) and autochthonous (recycled) nutrient sources to eutrophication and hypoxia and anoxia is not well understood.

- Many current analytical methods for nutrients are inadequate, or if adequate, are not widely used.

<u>Recommendations</u>:

Sources

- Additional information would allow one to determine the significance of atmospheric and groundwater sources of nutrients in estuaries and coastal areas.

- Research to determine the significance of seasonal runoff and aperiodic storms as sources of nutrients and their role in controlling rates of production in marine ecosystems would generate information to improve our understanding in this area.

- To determine the role of allochthonous (external) versus autochthonous (recycled) nutrient inputs to a water body and the subsequent changes in water quality and ecosystem response would require additional study.

System Response

- Further research would improve our ability to determine the conditions under which either phosphorus or nitrogen limit primary productivity in coastal, estuarine, and Great Lakes ecosystems.

- Additional research would elucidate the nature and degree of trophic structure changes resulting from excessive nutrient inputs.

Measurement Methodologies

- In order to adequately measure nutrients and their effects on the marine environment, improved analytical methods with more accuracy and precision should be developed.

Goal 3: Biological Agents

<u>Conclusions</u>:

- For many outbreaks of disease and mass mortalities of living marine resources, the specific biological agent responsible or the mechanism of impact is not known.

- The basic biological attributes of many biological agents, such as life history, environmental requirements, taxonomy, and persistence in the marine environment, are unknown.

- The importance of natural events and human activities and the environmental conditions necessary for the occurrence of mass mortalities and disease outbreaks in living marine resources are often not understood.

- o Very little is known concerning the survival and effects of genetically engineered organisms in the marine environment.

<u>Recommendations</u>:

Identifying Causative Agents

- o In those cases where there are observable events leading to disease outbreaks or mass mortalities (e.g., dolphin beachings) and there is no understanding of the cause, the most useful research would be directed toward identifying the agent responsible.

- o If a biological agent is suspected of causing an impact on marine resources, but evidence linking the agent to disease or mortality is lacking, the most valuable studies would assist in determining whether a cause and effect relationship exists.

Understanding Biological Attributes of Disease-Causing Agents

- o In those cases where a biological agent is known to affect marine organisms but knowledge concerning the impact is incomplete, the most useful research would focus on determining the connection between biological agents and natural events or human activities causing the outbreaks, as well as on quantifying the extent of the impact on marine organisms. Such research should address the following issues:

  - Persistence and transport mechanisms;
  - Host range and vectors/alternate hosts;
  - Host defense mechanisms and virulence of pathogen;
  - Role of environmental factors on pathogen interaction; and
  - Development of rapid diagnostic techniques.

Mitigating Effects

- o Once the impact of a biological agent on living marine resources is better understood, the highest research priority should be assigned to learning how to avoid or mitigate those impacts. Such research should include a determination of:

  - Control points and mechanisms of pathogenicity of the biological agents;
  - Population genetics;
  - Population dynamics of host and pathogen;
  - Host range and response;
  - Production of toxins or metabolites; and
  - Complex interactions with other pathogens, hosts, or chemical pollutants.

Goal 4: Loss or Modification of Marine Habitats

Conclusions:

- The U.S. Fish and Wildlife Service wetland maps and estimation of wetland loss rates derived from these maps are as much as 10 years out of date and do not provide timely information on the status and trends of habitats in areas of most rapid change.

- Although for the most part we know which causes, both natural and anthropogenic, result in habitat loss and modifications, we have not adequately quantified the human activities that are affecting wetlands, nor, in most cases, are we able to accurately predict how natural events or human activities will impact habitats.

- Researchers do not have an adequate understanding of estuarine processes and their importance to habitat functions.

- Without an adequate understanding of the natural processes and functions of habitats, we cannot accurately determine the effects that human activities will have on habitat quantity and quality, nor can we determine how well mitigation efforts actually replace the functional values of lost habitat.

- A key issue for future habitat research will be to understand the cumulative effects of numerous projects over time and space on the quantity and quality of marine and estuarine habitats and the ecosystem.

- Adequate information is not available to assess the effects of persistent marine debris on populations of living marine resources.

Recommendations:

Status of Habitat Quality

- The National Wetland Inventory (NWI) maps for coastal areas undergoing rapid change should be updated as frequently as needed.

- The Federal Government should consider methodologies for the development of high-resolution, geo-referenced digital database systems for critical coastal habitat types.

- Better inventories of selected subtidal and endangered species habitats would provide important information for the management of fisheries, valued species, and environmental quality.

- Ongoing and planned work at the national level to document trends in wetland loss should be continued.

Causes of Habitat Loss

- Analyses to identify and quantify human activities causing physical alterations that result in habitat loss and modification would provide valuable management information.

Natural Processes and Habitat Functions

- Research to understand habitat processes and functions as related to living marine resource productivity and the effects of human activities on these processes and functions should be continued.

Effects of Habitat Loss

- A better understanding of the long-term effects of specific projects as well as the cumulative effects on a regional basis would improve our ability to manage resources.

- Models to assist in predicting the effects of sea-level rise on marine and estuarine habitats and to predict changes in accretion, erosion, and sedimentation affecting habitat that result from human activities would contribute to the Nation's ability to manage coastal environments in the long term.

Effectiveness of Mitigation Measures

- Improved approaches would allow us to better assess the effectiveness of mitigation and restoration techniques in terms of the quality of the restored habitat.

Marine Debris

- Research to identify and quantify the effects of marine debris on populations of living marine resources and to determine the level of land-based contributions to the marine debris problem would improve our understanding in this area. Monitoring efforts should be conducted to determine the rates of marine debris entanglement and ingestion by wildlife. Techniques should be developed to reduce the impact of fishing gear entanglement and for the handling of ship-generated waste and reduction of land sources of marine debris.

Goal 5: Status of Marine Ecosystems

Conclusions:

- A number of stress responses at the organism and suborganism level show potential for use in marine programs, while others need further development.

- Current indicators of pollution stress at the population, community, and ecosystem levels often cannot adequately distinguish natural fluctuations from pollution effects or determine when observed changes or differences are of concern.

- Results obtained from monitoring studies indicate that it is feasible and useful to document the status and trends of contaminant levels in living and nonliving components of marine ecosystems.

- There are gaps in our knowledge concerning the impact of hydrographic factors (such as freshwater inflow and sediment loading) on marine ecosystems.

<u>Recommendations</u>:

Changes in Biological Status

- o Work should continue to develop and field test the most promising indicators of pollution stress on individual organisms.

- o Basic research and development activities designed to increase the utility of indicators of pollution stress at the population and community level should continue.

Changes in Physical and Chemical Factors

- o Measurements of contaminant-level trends in water, sediment, and biota should continue to be made. Additional summaries of historical contaminant concentrations should be developed to compare and to interpret recent measurements.

- o Information needs have been identified in the following areas concerning the significance to marine and estuarine ecosystems of changes in hydrographical parameters:

  - Effects of changes in freshwater inflow on secondary productivity;

  - Relationship between freshwater inflow and low dissolved-oxygen and pollutant concentrations;

  - Effects of land-use changes on sediment loading; and

  - Effects of sediment loadings on secondary productivity.

Coordination

- o The Federal Government should promote coordination of state and regional programs, develop guidelines for use in standardizing monitoring techniques, and support useful analyses of historical and encountered data.

Goal 6: Human Health

<u>Conclusions</u>:

- o Existing Federal and state monitoring programs provide limited data on the concentrations of chemical contaminants in edible tissues of commercial and recreational fish species. In addition, it is difficult to set "acceptable" limits for chemical concentrations in seafood because of uncertainties in our information on toxic response in humans, seafood consumption patterns in the United States, and exposure through other routes. Regulatory programs could be made more effective if these inadequacies were resolved.

- Governmental programs, such as the National Shellfish Sanitation Program, have been largely effective in protecting the public from diseases such as hepatitis, cholera, and typhoid, as well as from biotoxin poisoning associated with the consumption of molluscan shellfish. However, sporadic outbreaks of illness, primarily associated with free-living, opportunistic Vibrio species and gastroenteritis-causing viruses still occur.

- Traditionally used microbial water quality indicators do not predict the occurrence of viral pathogens and naturally occurring pathogenic bacteria such as V. vulnificus.

- Current information suggests that exposure to chemical pollutants during swimming and diving and through occupational activities related to seafood do not pose significant risks to human health in the United States at this time.

- Current methods for the removal and inactivation of human pathogens are effective in controlling the input of bacterial pathogens to the marine environment but not for other important pathogens such as the Norwalk-like viruses.

- Seafood consumption advisories, shellfish bed closures, and beach classifications are issued by state and local governments using largely inconsistent methods. Public responses to such advisories display wide differences in comprehension and compliance.

Recommendations:

Chemical Contaminants

- More comprehensive information on concentrations of significant contaminants occurring in the major commercial and recreational species would be useful. In addition to increasing temporal and geographical intensity of sampling, monitoring programs would be improved by establishing standard methods for sampling and analysis of seafood.

- Updating information on seafood consumption patterns in the United States, especially for high-risk geographical or cultural populations, would improve our ability to carry out risk assessments.

- Although progress will be difficult, research should continue in the following areas to increase the understanding of the interactive effects of chemical mixtures on human health:

  - Concentrations of toxic substances in mixtures;

  - Toxicity to humans of individual contaminants; and

  - The influence of environmental processes and interactions on toxic response.

Pathogens

- Research should continue to determine which marine pollution-related pathogens are causing human health effects. Efforts to improve our ability to monitor seafood and water quality for human pathogens should also continue.

- o Identification of improved indicators of microbial contamination of seafood and marine water would enhance our capability to manage human health risks. These indicators should be validated on the basis of statistical data on disease incidence.

- o Region-specific studies may be necessary to determine the relative importance of local sources of human pathogens to the marine environment.

Management Tools

- o Studies conducted in selected regions of the country would allow us to more accurately determine the effectiveness of health advisories in reducing human health risks from consumption of contaminated seafood.

- o Studies conducted to determine when approved shellfishing areas are safe should focus on viruses and naturally occurring pathogens.

- o Additional studies would be helpful in assessing the effectiveness of beach closures in protecting swimmers from diseases caused by pathogens.

Hazardous Materials

- o Research efforts should continue to develop comprehensive performance standards for chemical-protective suits worn by personnel during chemical spill clean-up activities, and to design more chemically resistant suits.

PRIORITIES FOR ACTION BY THE NATIONAL OCEAN POLLUTION POLICY BOARD

In addition to making specific research and monitoring recommendations for achieving each of the goals of the National Program, this Plan also presents an "agenda for action" for the National Ocean Pollution Policy Board to pursue during the interim between Federal Plans. The items presented in the agenda are specific and implementable tasks that the Board can initiate on its own through cooperation among member agencies.

The "agenda for action" is a new feature not found in previous 5-year Plans. It is designed to help assure the Board's continuing involvement in implementing recommendations found in the Plan between now and the submission of the next Plan 3 years later. The proposed "agenda for action" includes two types of agenda items. The first category comprises a specific task, such as a study or report. The second involves the formation of an ad hoc working group of Federal and outside specialists to develop and implement a strategy for filling a specific need.

The following items constitute the Board's agenda for action:

Specific Tasks

Atmospheric Inputs of Toxic Substances. The Board will conduct and publish a state-of-the-art review concerning the sources, routes, and environmental significance of atmospheric inputs of selected toxic substances to the marine environment. The study will identify societal trends and technological developments that might influence future atmospheric inputs and assess the implications of these changes for the next 25 years. The report will also include a description of research needs and priorities for improved understanding of this issue. The study will be supported jointly by a group of interested Board agencies and directed by an ad hoc committee of Federal experts in this area.

Future of Coastal Areas. The Board will support a strategic assessment of future environmental problems in the Nation's coastal areas. The purpose of the study is to predict the most important environmental problems that will be faced by estuarine and coastal ecosystems over the next 50 years. The study will be conducted under the direction of a steering group of Federal, academic, industry, and environmental experts. The study will consider population growth and shifts to coastal areas, changes in industrial practices, future waste disposal requirements, economic development, technological improvements, and global changes in environmental quality and climate.

Seafood Consumption Patterns. The Board will support a study to update information on seafood consumption patterns in the United States and to identify population sectors (geographical, cultural, professional) at high risk from consumption of seafood contaminated with toxic substances. The study will evaluate the effectiveness of existing guidelines for limiting consumption of contaminated seafood in protecting high-risk sectors of the population. The study will also identify high-priority research needs related to this issue. The study will be conducted under the direction of the Board.

Indicators of the Presence of Human Pathogens. Estimates of the concentrations of fecal coliform bacteria have been traditionally used to indicate the presence of human pathogens in coastal waters. However, this indicator is not considered accurate by many experts, especially for health risks associated with viral diseases. The Board will support the development of improved indicators of human pathogens in the marine environment.

Ad Hoc Working Groups

Monitoring Environmental Quality of Marine Ecosystems. Better information on the status of marine ecosystems could be collected to provide an "early warning system" to environmental managers. The Board will establish an ad hoc committee of Federal and private scientists and program managers to examine the availability of such information to environmental managers. The committee will:

- Establish the objectives of the Federal program in this area and determine appropriate roles at the Federal and state levels of government.
- Propose a systematic strategy for developing a national monitoring capability to meet these objectives. The strategy will incorporate existing national and regional programs, use of encountered data, peer review, and information synthesis and dissemination.
- Promote the development of improved indicators of ecosystem status.

The committee will report to the Board and recommend actions to be taken by the Board.

Habitat Loss or Modification. Loss or modification of emergent vegetation and submerged aquatic vegetation is a major problem threatening the marine resources of the Nation. The Board will establish an *ad hoc* committee to:

- Assure that National Wetlands Inventory (NWI) habitat maps in areas of rapid habitat loss are updated as frequently as necessary.
- Evaluate the costs, benefits, and approaches for developing a high-resolution, geo-referenced digital database for use in planning and documenting coastal alterations.
- Assure that regional and national trends in habitat loss and modification are adequately documented.
- Support research necessary to develop the capability to predict the effects of sea level rise on coastal habitats.
- Support a state-of-the-art review regarding the effectiveness of mitigation and restoration practices, particularly with regard to quality of habitat.
- Prepare a program development plan for increasing our understanding of habitat functions and processes.

The committee will report to the Board on a regular basis regarding progress, problems, and needs for personnel, resources, or other types of assistance that might be required.

Biological Agents. The Board will conduct an evaluation of the Nation's ability to perform research on the effects of biological agents on marine organisms. The study will be supported by several Board agencies and directed by an *ad hoc* group of Federal and outside specialists. The purpose of the study is to:

- Identify and assign priorities to research needs in this area.
- Evaluate the adequacy of existing facilities to conduct secure (P3) biological research.
- Assess capabilities for quick scientific response to investigate episodic events.
- Evaluate the need for a common database to promote sharing of information on the occurrence and effects of biological agents.
- Publish an annual review of the state-of-the-art and tally of the incidence of disease in marine biota.

The committee will report to the Board and recommend actions to be taken by the Board.

I. INTRODUCTION

INTERAGENCY COORDINATION

The National Ocean Pollution Planning Act (NOPPA) of 1978, P.L. 95-273 (as amended), requires the National Oceanic and Atmospheric Administration (NOAA) to prepare a "comprehensive 5-year plan for the overall Federal effort in ocean pollution research and development and monitoring" and to revise and update the plan every 3 years (Section 4). The National Ocean Pollution Program Office (NOPPO) was established by NOAA to execute the mandate of Section 4 by providing a focal point for the coordination of Federal efforts in marine pollution. Amendments to NOPPA in the Omnibus Budget Reconciliation Act of 1986 (P.L. 99-272) established the National Ocean Pollution Policy Board (formerly the Interagency Committee on Ocean Pollution Research, Development, and Monitoring) to promote interagency participation in the planning process as required under Section 7 of the Act. To meet the mandate of Section 4, NOPPO has prepared, in consultation with the Policy Board, this 5-year Federal Plan for the National Marine Pollution Program. It is the fourth such document produced since Congress passed NOPPA in 1978.

One of the primary purposes of NOPPA is "to develop the necessary base of information to support, and to provide for, the rational, efficient, and equitable utilization, conservation, and development of ocean and coastal resources" [Section 2(b)(2)]. The Act defines ocean and coastal resources to include essentially all components and aspects of the marine and Great Lakes environments under Federal jurisdiction. Among the common marine resources of direct use to man are:

- o Biological resources such as shellfish, finfish, and macroalgae;

- o Mineral resources of the continental shelf such as petroleum, sand, and gravel;

- o Drinking water from the Great Lakes;

- o Aesthetic and recreational resources used for swimming, fishing, and boating;

- o Resources related to the capacity of the marine environment to accept certain types of disposed wastes without adverse change; and

- o Maritime shipping and transportation routes.

In common usage, the term pollution has assumed a variety of meanings and applications. Under NOPPA, ocean pollution is defined as "any short-term or long-term change in the marine environment," where changes (usually adverse) are caused by human activity. The basic type of pollution effects in the marine environment that are of concern include:

- o Negative effects on marine biota at the individual, population, community, or ecosystem levels;

- o Effects that decrease the continued availability of marine resources for human use (e.g., contamination of fish or drinking water resources in the Great Lakes); and

- o Negative effects on human health.

A variety of human activities contribute to marine pollution and jeopardize the continued availability of marine resources. These activities include the disposal of dredged material, sewage, and industrial wastes; recovery of oil and gas from the continental shelf; marine transportation; and marine mining. Pollution may also be linked to nonpoint sources and accidental spills. Physical alterations of marine habitats by human activities are also considered to be marine pollution because they often result in negative effects, such as the loss of living marine resources.

This document addresses pollution research, development, and monitoring programs in coastal waters, estuaries, open oceans, and the Great Lakes. It identifies opportunities for future pollution studies.

GOALS OF THE NATIONAL PROGRAM

The Federal Plan for Ocean Pollution Research, Development, and Monitoring: FY 1981-1985 (NOAA, 1981) identified the following three broad policies of the Federal Government regarding ocean use:

- o Ocean Resource Use Policy -- Encourage the use of oceans, estuaries, and Great Lakes as sources of food, water, energy, and minerals and as a maritime medium in such a way that there is no significant adverse impact on human health, productivity, or aesthetic quality.

- o Ocean Waste Disposal Policy -- Consider, along with other options, the use of the oceans, estuaries, and Great Lakes as repositories for the disposal of waste material and thermal energy when it is determined that no significant impact to human health, productivity, or aesthetic quality would result.

- o Ocean Conservation Policy -- Preserve and enhance the productivity and aesthetic quality of the oceans, estuaries, and Great Lakes.

Table 1 lists the primary agencies that perform research and monitoring related to marine pollution, and identifies for each agency the major pieces of legislation that assign responsibilities for marine pollution research and monitoring. Each of these pieces of legislation is grouped within the ocean resource, ocean waste disposal, or ocean conservation policy categories, although several of these individual laws give mandates in more than one of these areas.

The National Marine Pollution Program is the composite of all the marine pollution research, development, and monitoring programs conducted by the Federal Government. The purpose of the National Program is to provide resource managers and decision-makers with scientific information about pollution phenomena needed to implement the three national ocean-use policies. To provide such information about marine pollution, the National Ocean Pollution Policy Board identifies the following broad goals for the National Marine Pollution Program:

1) Understand the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities;

2) Understand the sources, fates, and effects of nutrients entering the marine environment as a result of human activities;

3) Understand the sources, fates, and effects on marine organisms of biological agents that are introduced or influenced by human activities;

4) Understand the effects of losing or modifying marine habitats as a result of human activities;

5) Document the trends in the status of marine ecosystems; and

6) Understand the implications of marine pollution to human health.

The first four goals of the National Program address specific categories of pollutants or physical alterations to the marine environment (i.e., toxic materials, nutrients, biological agents, and habitat alterations). The last two goals (related to the status of marine ecosystems and human health) integrate the first four goals and permit the Plan to take into account all of the various contributions to marine pollution.

Marine pollution research, development, and monitoring programs funded by Federal agencies may be considered as contributing to these six areas of endeavor. To meet these goals, the scope of the programs undertaken may include the following:

Table 1. Federal Agencies with Major Legislative Mandates for Marine and Great Lakes Pollution Research and Monitoring

LAWS	AGENCIES								
	EPA	NOAA	USDA	DHHS	USCG	COE	MMS	FWS	DOE
Ocean Resource Use Policy									
Outer Continental Shelf Lands Act							X		
Deep Seabed Mining Act		X							
Federal Non-Nuclear Energy Research & Development Act									X
Atomic Energy Act									X
Fishery Conservation & Management Act		X							
Food, Drug & Cosmetic Act				X					
Safe Drinking Water Act	X								
Ocean Waste Disposal Policy									
Marine Protection, Research & Sanctuaries Act	X	X			X	X			
Water Quality Act	X		X		X	X			
Ocean Conservation Policy									
Fish & Wildlife Coordination Act		X						X	
Marine Mammal Protection Act		X						X	
Endangered Species Act		X						X	
National Environmental Policy Act	X	X	X	X	X	X	X	X	X

a) Assess the state of the environment

- Acquire basic understanding;

- Perform long-term baseline measurements to establish points of reference (e.g., look for natural variability);

- Identify and characterize the pollutants (e.g., in water, in sediments);

- Assess pollutant transport and fate. This includes research and development on processes of pollutants and their interactions with the environment;

- Determine effects on living resources, wetlands and habitats, and humans; and

- Implement monitoring systems to obtain temporal and spatial information concerning effects of human activities.

b) Develop the capability to estimate or predict

- Pollutant inputs;

- Pollutant trajectories and fate; and

- Impacts of existing and future activities.

c) Develop multipurpose program support capabilities to assist agency programs and to promote consistency (e.g., quality assurance of chemical measurements in the marine environment, development of measurement methods).

Priorities within these areas will change through time as new pollution problems emerge and as information about existing problems is accumulated and judged to be sufficient. Evaluation of the existing and planned Federal effort in each of the six goal areas enumerated above is presented in Chapter III of the Plan.

The National Marine Pollution Program also adopts the following two management objectives: (1) to maximize the effectiveness of Federal marine pollution research, development, and monitoring programs by assuring that such programs address national needs and problems in a manner that is consistent with the urgency of the need for information, and (2) to maximize the efficiency of Federal marine pollution research, development, and monitoring programs by eliminating or reducing unintentional duplication of effort, making maximum use of existing capabilities, and by promoting coordination and cooperation among Federal programs through more effective use of available funds, research, personnel, vessels, facilities, and equipment. The National Ocean Pollution Policy Board aims to promote both management objectives.

THE PLANNING PROCESS

The Federal Plan for Ocean Pollution Research, Development and Monitoring is required by Section 4 of NOPPA to provide several specific types of information:

- o Identify national needs and problems relating to ocean pollution;
- o Establish priorities in addressing these needs and problems;
- o Describe the Federal programs and projects related to marine pollution; and
- o Make recommendations for changes in the overall Federal effort in ocean pollution research and monitoring to assure that priority national needs and problems are met by Federal programs during the Plan period.

The planning process undertaken during the development of this Plan is shown in Figure 1. In early 1987, NOPPO conducted a national marine pollution priorities study involving 145 individuals from the Federal Executive and Legislative Branches, state and local governments, academia, ocean industries, and environmental interest groups. The priorities identified by this study were emphasized at a national workshop convened in Easton, Maryland, in June 1987. The workshop was divided into five working groups:

- o Habitat modification and loss;
- o Pipeline disposal of municipal wastewater;
- o Pipeline disposal of industrial wastes;
- o Nonpoint source pollution; and
- o Persistent marine debris.

The general findings stated that:

- o The ability to gauge progress toward implementation of a Plan should be improved;
- o Involvement of the non-Federal sector during Plan preparation should be promoted; and
- o Synthesis and dissemination of existing data and information should be emphasized.

Additional information concerning the findings and recommendations of the workshop are presented in the workshop proceedings (NOAA, 1988).

Using the workshop findings and existing Federal ocean policies, NOPPO (with the guidance and approval of the National Ocean Pollution Policy Board) identified the six specific National Program goals stated above. In late 1987 and early 1988, working groups were formed to aid in development of the sections of the Plan that deal with each goal. These groups consisted of Federal representatives and experts from the non-Federal sectors. The members of each of the working groups are identified in Appendix A.

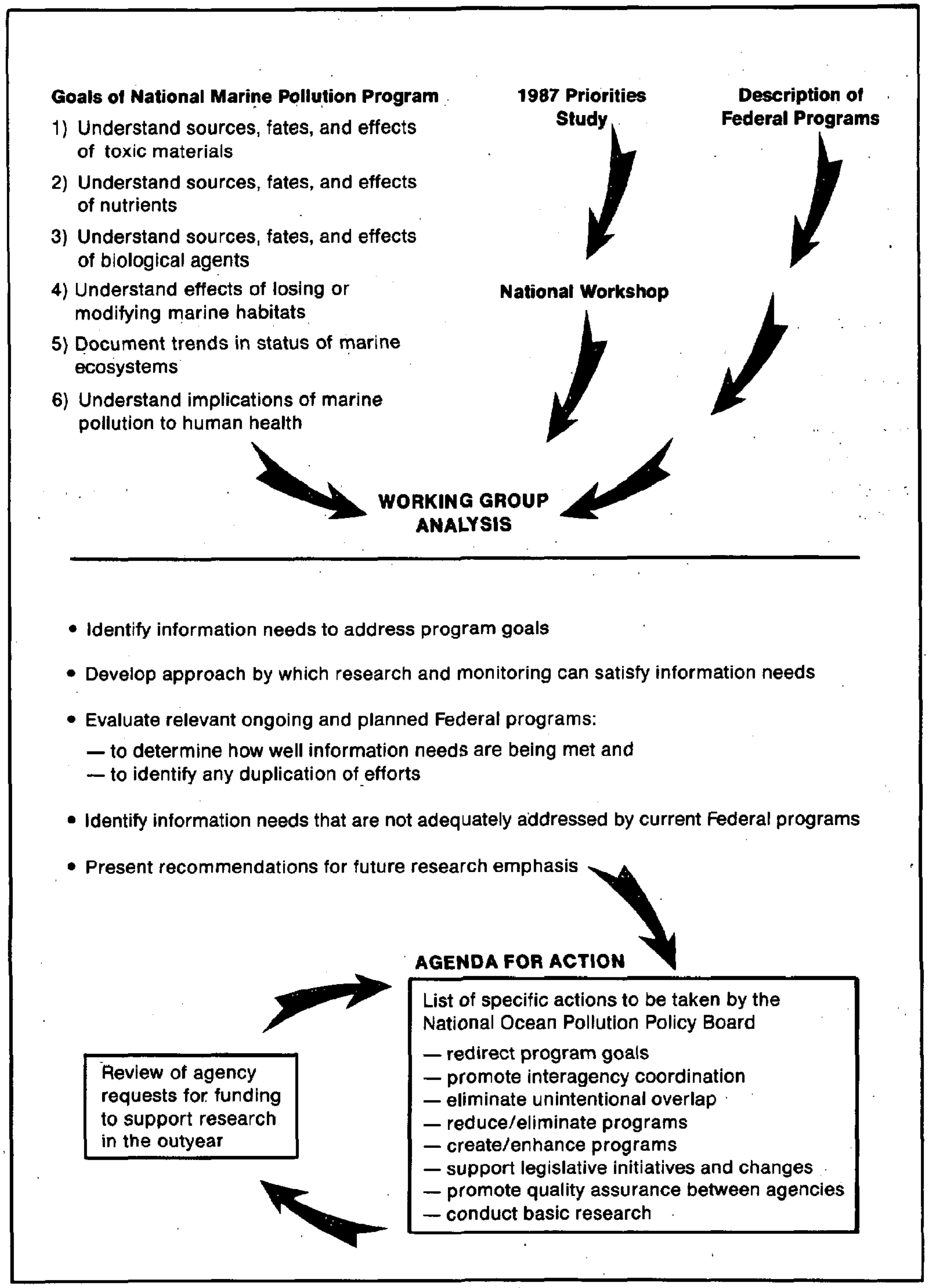

Figure 1. The Planning Process.

Each of the six working groups met twice to assist NOPPO in the drafting of the Plan. The working groups were asked to provide guidance on the state-of-the-art, information needs, and research recommendations pertaining to each of the six topics. The discussions and findings presented in the Plan may have been altered during the official review by the National Ocean Pollution Policy Board; therefore, it should not be assumed that this final version of the Plan necessarily reflects the total consensus of the working groups.

PURPOSE AND LIMITATIONS OF THE PLAN

Many Federal departments and agencies are required by law to conduct marine pollution studies, and each must fulfill the requirements of its specific missions and obligations. Programmatic decisions on areas of research emphasis within each agency are made through competition among many priority areas, and research programs must be related to agency missions. The Plan is not intended to override or interfere with the responsibilities and mandates of individual agencies. However, a responsive and efficient Federal program of marine pollution research can be achieved by ensuring that important research areas are not overlooked if they fall between agency jurisdictions, and that related programs are carried out cooperatively and without duplication. As a strategy document, the Plan is not intended to provide a detailed tactical implementation scheme. Ultimately, it is up to the discretion of individual agencies to accept and implement the general mandate of NOPPA by cooperating in a coordinated national effort in marine pollution research and monitoring, and it is up to the individual agencies involved in the National Marine Pollution Program to accept and execute the recommendations offered in the Plan.

The Policy Board conducts an annual review of agency appropriation requests as submitted to the Office of Management and Budget (OMB). Each agency involved in the National Marine Pollution Program is required under Section 4 of NOPPA to prepare and submit to the Policy Board, at the same time that its budget is submitted to OMB, information on annual requests for appropriations to support ocean pollution research, development, and monitoring programs. The requests for appropriations are reviewed by the Policy Board, which subsequently submits a report to OMB as the President's agent and then to the Congress concerning how these budget requests assist in attaining the program goals stated in this Plan. Under NOPPA, OMB reviews the requests for appropriations as an integrated, coherent, multiagency request and is to take into account the review of the Board.

The conclusions and recommendations of this Plan have been reviewed, discussed, and accepted by the Policy Board. This ensures compatibility between the Plan and the individual mandates of each agency in order to facilitate its implementation. During the interval between editions of the Plan, the National Ocean Pollution Program Office works with the Policy Board agencies to promote implementation of recommendations in selected priority areas.

ORGANIZATION OF THE PLAN

Chapter II is an overview of the National Marine Pollution Program; it includes summaries of agency activities and responsibilities and an overview of program expenditures. This chapter also includes a discussion of marine pollution funding trends.

The focus of the Federal Plan for Ocean Pollution Research, Development, and Monitoring: FY 1988-1992 is in Chapter III. In this chapter is a discussion of the goals of the National Marine Pollution Program as cited above. This approach is different from the last Plan in which the discussion focused on activities that may cause pollution. The six goals take into account the various polluting activities and pollutants of concern. The discussion of each goal includes examination of the goal rationale, listing of relevant agency programs, identification of research and information gaps, and recommendations for future research to address these gaps.

Chapter IV contains an "agenda for action" by the National Ocean Pollution Policy Board during the 3-year interim between the development of 5-year plans. This agenda will help assure that the Plan will be used and will aid in the measurement of progress toward achieving the goals set forth in the Plan. The agenda allows for the inclusion of more detailed program evaluation and planning and provides specific opportunities for interagency and State/Federal coordination.

Literature Cited

NOAA. 1981. National Marine Pollution Program Plan - Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1981-1985. National Marine Pollution Program Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, MD. 185 pp.

NOAA. 1988. Proceedings: National Marine Pollution Problems and Needs Workshop, Easton, Maryland. June 9-11, 1987. National Ocean Pollution Program Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, MD. 53 pp. + Appendices.

II. THE NATIONAL MARINE POLLUTION PROGRAM

This chapter presents an overview of the federally funded programs in ocean pollution research, development, and monitoring that comprise the National Marine Pollution Program. An analysis of funding trends for the entire National Marine Pollution Program from FY 1984 through FY 1988 is presented along with the funding requested for FY 1989 in the Presidential budget. The chapter includes descriptions of the pollution programs of the 11 Federal departments and agencies that conduct marine pollution research, development, or monitoring activities.

OCEAN POLLUTION FUNDING TRENDS: FY 1984-1989

The following Federal agencies and departments support marine pollution-related research, development, or monitoring activities:

Council on Environmental Quality
U.S. Department of Agriculture
U.S. Department of Commerce
  National Institute of Standards and Technology
  National Oceanic and Atmospheric Administration
U.S. Department of Defense
  U.S. Army Corps of Engineers
  U.S. Navy
U.S. Department of Energy
U.S. Department of Health and Human Services
  Food and Drug Administration
  National Institute of Environmental Health Sciences
U.S. Department of the Interior
  Minerals Management Service
  U.S. Fish and Wildlife Service
  U.S. Geological Survey
U.S. Department of Transportation
  U.S. Coast Guard
U.S. Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation

Between FY 1984 and FY 1988, Federal marine pollution funding decreased by $13.9 million or 12% (Figure 2). This reflects the Administration's efforts to eliminate unnecessary and duplicative programs and those programs that have satisfied their legislated mission.

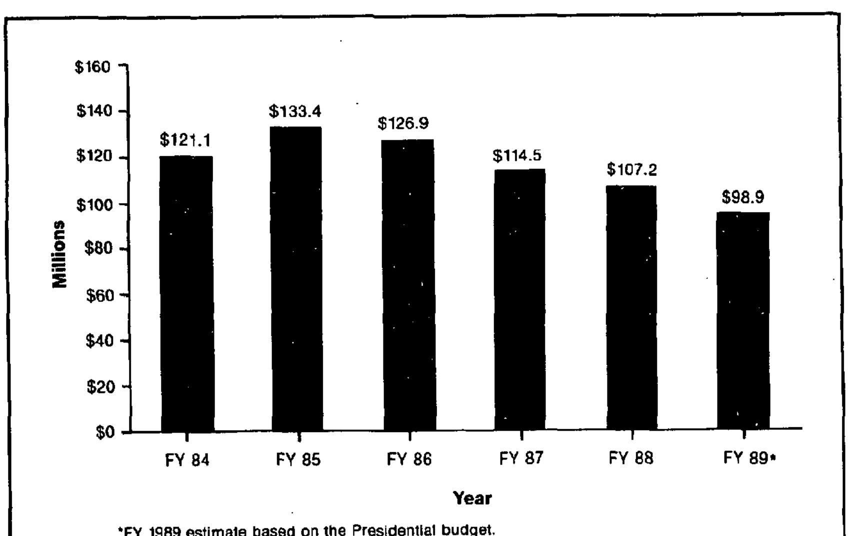

Figure 2. Total Funding for the National Marine Pollution Program, FY 1984 - FY 1989.

During this 5-year period, 5 of the 11 Federal departments and agencies involved in marine pollution research experienced reductions in pollution funding amounting to $33.0 million; 4 received increased funding amounting to 16.1 million; 1 (U.S. Department of Agriculture) was level funded (although it changed its reporting procedure to include a greater portion of its program); and 1 (Council on Environmental Quality) began reporting a portion of its program for inclusion in the National Marine Pollution Program for the first time (Table 2). Of those agencies with increased funding, the U.S. Environmental Protection Agency (EPA) accounted for $15.4 million of the increases (Figure 3).

Most of the 95% increase in EPA marine pollution funding that occurred between FY 1984 and FY 1988 ($16.3 to 31.7 million) resulted from the creation and funding of the National Estuary Program. In addition, a large portion of this increase resulted from the increased funding of Water Quality and Great Lakes research.

Other agencies experiencing increases in marine pollution funding between FY 1984 and FY 1988 were the U.S. Department of Health and Human Services (DHHS) (<$0.1 million or 2%), the U.S. Coast Guard ($0.3 million or 22%), and the National Aeronautics and Space Administration (NASA) ($0.3 million or 129%). The DHHS increased spending resulted from a slight increase in funding for the Shellfish Sanitation Program. The increase in Coast Guard spending resulted from increases in the budget of the Marine Environmental Response Program. NASA's increased spending resulted from an increased budget for the Ocean Productivity Program for the development and utilization of space-borne technologies. The apparent increase of $3.0 million for the U.S. Department of Agriculture (USDA) does not reflect an actual increase in research level. Starting in FY 1985, the USDA changed its reporting procedure to include a greater portion of its program.

Between FY 1984 and FY 1988, the U.S. Department of Energy's (DOE) marine pollution funding decreased more than any other Federal agency's ($12.7 million or 69%) (Figure 4). All but one DOE marine pollution-related program was either reduced in funding during this period or eliminated entirely. Funding for the Regional Marine Program increased slightly, while funding for the Physiological Ecology Program decreased and the Ocean Thermal Energy Conversion Program, Radioecology Program, Strategic Petroleum Reserve Program, Subseabed Disposal Program, and Arctic and Offshore Research Program were all zero funded in FY 1988 or were eliminated between FY 1984 and FY 1988.

Other agencies experiencing reductions in marine pollution funding between FY 1984 and FY 1988 included the U.S. Department of the Interior (DOI) ($11.4 million or 31%); U.S. Department of Commerce (DOC) ($5.6 million or 18%); U.S. Department of Defense (DOD) ($2.0 million or 17%); and National Science Foundation ($1.3 million or 89%). Within DOI, the Minerals Management Service experienced a $10.7 million (37%) reduction in marine pollution funding, and the U.S. Geological Survey experienced a $2.8 million (50%) reduction. The U.S. Fish and Wildlife Service of DOI showed an increase in funding during this period due to the inclusion of funding for the National Wetlands Inventory beginning in FY 1985. Much of the reduction in DOC's marine pollution funding resulted from a decrease in ship support for the National Oceanic and Atmospheric Administration (NOAA). Other NOAA programs experiencing decreases in funding between FY 1984 and FY 1988 include the Coastal and Estuarine Assessment Program, the ERL Ocean Pollution Program, and the National Fishery Ecology Program. In spite of the overall decrease in NOAA marine pollution funding, several NOAA programs received increased funding, including the Strategic Assessment Program and Sea

Table 2: National Marine Pollution Program Funding Levels: FY 1984 - 1989 (funding in thousands of dollars)

Agency	FY 1984 Estimates	FY 1985 Estimates	FY 1986 Estimates	FY 1987 Estimates	FY 1988 Estimates	FY 1989 Presidential Budget
CEQ*	0	19	11	9	9	0
USDA**	196	3,400	3,354	3,139	3,167	3,441
DOC						
NIST	0	0	0	0	0	0
NOAA	31,008	39,443	35,859	32,988	25,420	15,597
DOD						
COE	10,135	9,504	8,064	8,996	8,500	9,990
Navy	1,600	1,920	1,900	1,575	1,235	720
DOE	18,513	18,831	13,650	6,895	5,767	6,127
DHHS						
NIEHS	923	1,277	452	470	486	503
FDA	2,470	2,421	1,941	2,491	2,959	2,990
DOI						
MMS	28,659	23,024	20,912	19,285	18,000	18,000
FWS	2,707	5,132	5,565	5,274	4,735	4,735
USGS	5,555	4,997	6,514	2,583	2,783	2,428
DOT						
USCG	1,433	1,080	1,235	975	1,744	990
EPA	16,285	20,893	26,615	28,625	31,715	32,815
NASA	210	453	483	480	480	510
NSF	1,405	970	376	690	151	50
TOTAL	121,099	133,364	126,931	114,475	107,151	98,896

*Starting in FY 1985, the CEQ began reporting a portion of their program for inclusion in the National Marine Pollution Program.

**Starting in FY 1985, the USDA changed its reporting procedure to include a greater portion of its program. The funding increase between FY 1984 and FY 1985 results from this change and does not necessarily reflect an increase in research level of effort.

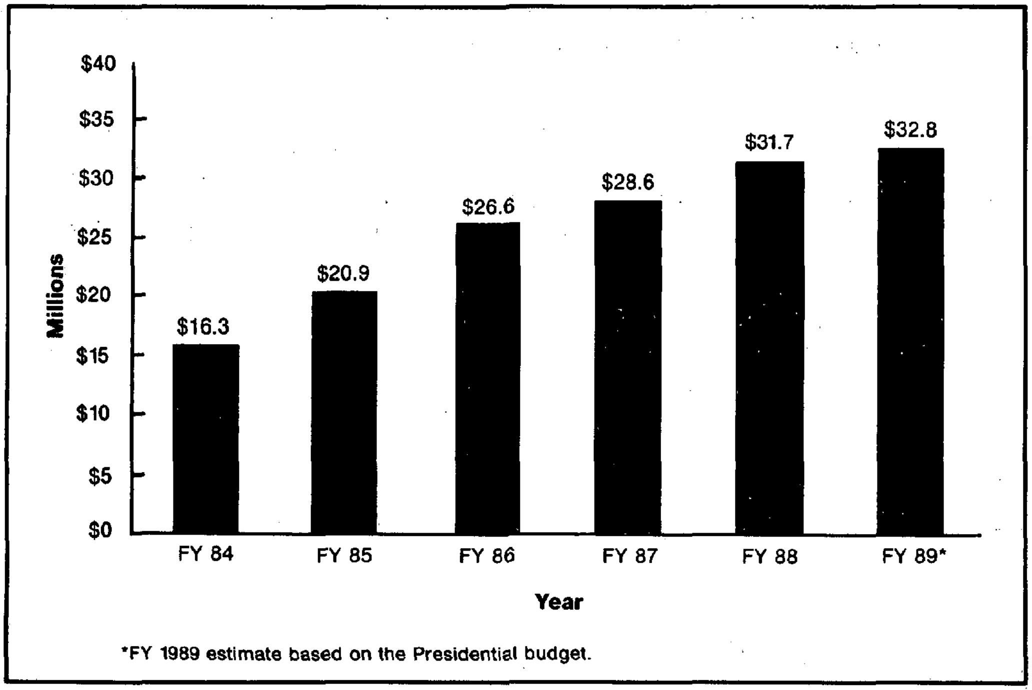

Figure 3. Trends in Funding for the Environmental Protection Agency, FY 1984—FY 1989.

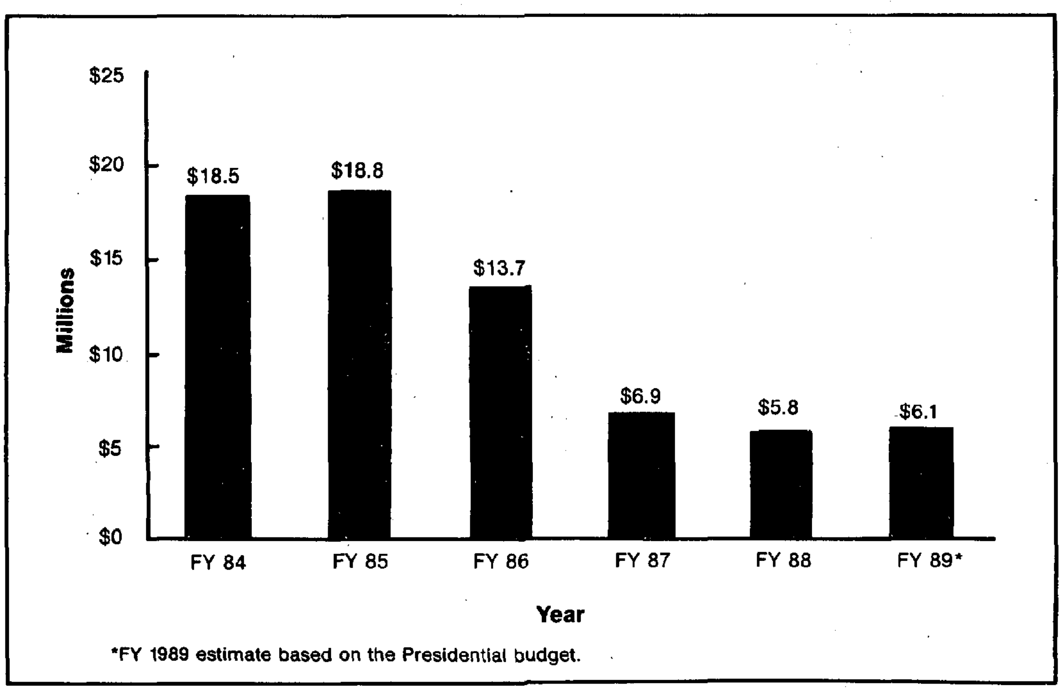

Figure 4. Trends in Funding for the Department of Energy, FY 1984—FY 1989.

Grant Ocean Pollution Program. The U.S. Army Corps of Engineers of DOD received $1.6 million less (16% decrease) for marine pollution research in FY 1988 than in FY 1984, while the U.S. Navy received $0.4 million less (23% decrease).

The President's FY 1989 budget request for marine pollution programs is $98.9 million, $8.3 million less than the FY 1988 level. Reductions in NOAA's ocean pollution programs would account for most of this decrease in funding (Figure 5). Other agencies that would experience decreases in funding for marine pollution studies under the proposed FY 1989 budget include the U.S. Coast Guard ($0.8 million or 43%). Under the proposed FY 1989 budget, the EPA would receive the largest increase in marine pollution funding ($1.1 million or 3%), and the DOD would receive an additional $1.0 million (10%).

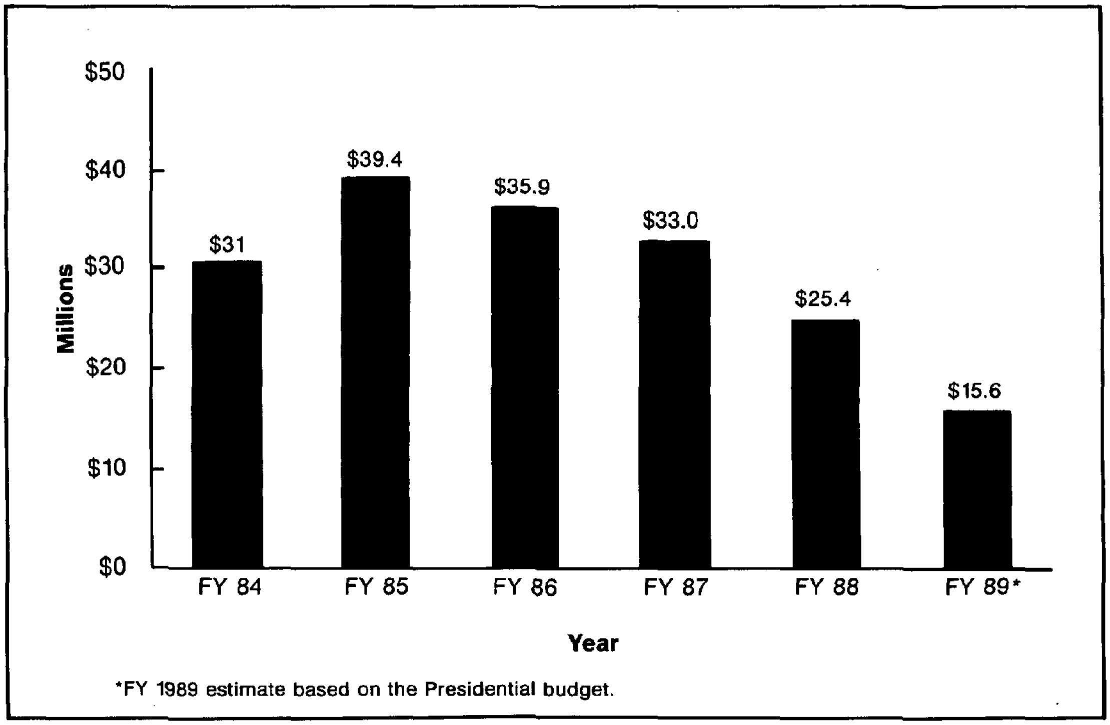

Figure 5. Trends in Funding for the National Oceanic and Atmospheric Administration, FY 1984—FY 1989.

AGENCY PROGRAMS

In FY 1988, the Federal Government expended over $107 million for marine pollution research, development, and monitoring activities. In FY 1988, EPA was the major supporter of marine pollution research, development and monitoring activities ($31.7 million or 30% of the total program) followed by DOI ($25.5 million or 24%) and NOAA ($25.4 million or 24%). The percentage of total marine pollution funding expended by each of the concerned agencies is presented in Figure 6.

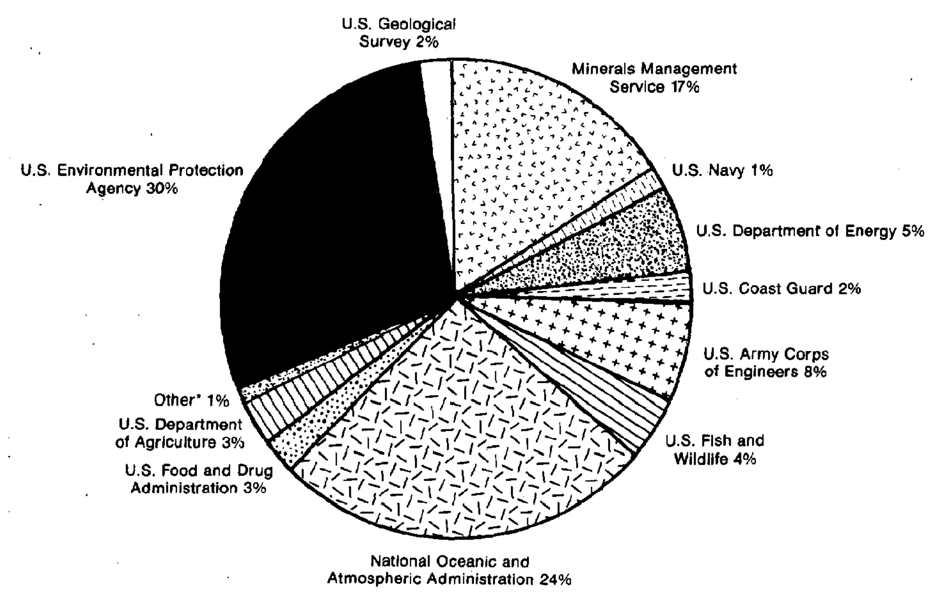

Figure 6. Percentage of Total FY 1988 Funding Provided by Individual Federal Agencies.

The following discussion presents an overview of the major responsibilities and activities of the Federal agencies involved in marine pollution research, development, and monitoring. Included are discussions of the major marine pollution programs within each agency and estimated FY 1988 funding levels of those programs. More detailed information will be available in a future edition of the <u>National Marine Pollution Program: Summary of Federal Programs and Projects</u>.

<u>Council on Environmental Quality</u>

The Council on Environmental Quality (CEQ) is required by the National Environmental Policy Act of 1969 to report to Congress annually on the status and condition of the environment, the current and foreseeable trends in the quality, management, and utilization of the environment, and the effects of environmental trends. In an effort to fulfill this Congressional mandate, CEQ has enjoined other Federal agencies to develop a sourcebook of environmental statistics that are indicative of current conditions and historic trends in the quality of the environment of the United States. The FY 1988 marine pollution-related funding provided by CEQ for this effort is approximately $9,000. This amount is augmented by funding from other Federal agencies.

U.S. Department of Agriculture

The overall science mission of the U.S. Department of Agriculture (USDA) is to conduct research, development, and education programs on problems related to agriculture production and to the protection of the environment. A portion of the USDA research effort addresses the effects of agricultural and resource development practices on the quality of the marine environment. The overall goals of this research are to aid in the effective management and use of the nation's soil, water, and air resources and on reducing pollutants in receiving streams, lakes, estuaries, and oceans. Research projects of the Agricultural Research Service, Cooperative State Research Service, and Forest Service are included in the National Marine Pollution Program.

The USDA expended $3.2 million on marine pollution research, development, and monitoring activities during FY 1988. Starting in FY 1985, the USDA changed its reporting procedure to include a greater portion of its program. The funding increase between FY 1984 and FY 1985 results from this change and does not reflect an actual increase in research level of effort. These funds were used to support research examining the effects of soil erosion, agricultural runoff, agricultural waste disposal, sedimentation, nutrients, and pesticides on marine organisms and ecosystems and the transport and transformation of pollutants. The projects are conducted through mechanisms of direct Federal research as well as support of cooperative efforts and grants. All relevant USDA projects have been grouped into the following three areas, which are listed as programs:

- Nonpoint Source Contaminants Program ($2.2 million) -- Conducts research on pollution problems caused by soil erosion, estuarine sedimentation, slope stability in agricultural and forested watersheds, streambank and shoreline stability, organic debris and turbidity, and on-land studies to prevent erosion from occurring.

- Habitat Modification Program ($0.9 million) -- Conducts research on improving the ability to evaluate the effects of watershed development projects on resource conservation, and investigations of landscape and channel modifications on ambient concentrations of sediments and agricultural chemicals in streams.

- Point Source Contaminants Program (less than $0.1 million) -- Conducts studies to investigate chemicals in bottom mud originating from dump sites and chemical plants, oil spills, and contaminants from other point sources.

U.S. Department of Commerce

National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) has responsibility for the custody, maintenance, and development of the national standards of measurement and the provision of means and methods for making measurements consistent with those standards. NIST cooperates with other Federal agencies for the development of standard practices and the establishment of reference bases in support of national programs. Within NIST, the Center for Analytical Chemistry performs research in analytical methods and standard reference materials, the provision of quality assurance services, and services to other agencies of the government. Many of the Center's services are applicable to ocean pollution research and monitoring programs. These include measurement of hazardous wastes, organic and inorganic species in water, organic and inorganic species in marine organisms and sediments, research in sampling, analytical design, and long-term storage of samples. Since all marine pollution-related activities at NIST are carried out on a reimbursable basis, no funding is listed in the National Marine Pollution Program for NIST's related activities.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) has legislative responsibilities for conducting research on problems caused by polluting activities in the oceans and the Great Lakes. During FY 1988, NOAA funded $25.4 million for marine pollution research, development, and monitoring studies under the Office of the Chief Scientist, the National Ocean Service, the Office of Oceanic and Atmospheric Research, the National Marine Fisheries Services; and the National Environmental Satellite, Data, and Information Service. The marine pollution programs of these organizations and their specific research responsibilities are as follows:

- o Office of the Chief Scientist

  - National Marine Pollution Coordination Program ($1.3 million) -- Coordinates ocean pollution research, development, and monitoring programs supported by all Federal departments and agencies.

  - Estuarine Program Office (0.6 million) -- Facilitates coordination of estuarine activities within NOAA and other Federal and state agencies.

- o National Ocean Service

  - Coastal and Estuarine Assessment Program ($5.7 million) -- Conducts national and regional studies in representative coastal regions and estuaries to develop improved methods for use by NOAA, other public agencies, and the private sector in assessing the effects of coastal and estuarine use activities throughout the Nation.

  - Strategic Assessments Program ($3.0 million) -- Conducts assessments of multiple ocean resource uses for the Nation and its major coastal and ocean regions to determine marine resource development strategies, which will result in maximum benefit to the Nation with minimum environmental damage or conflicts among uses.

  - Hazardous Materials Response Program ($2.3 million) -- Develops scientific plans and coordinates scientific input related to spills of hazardous substances occurring in coastal waters, the 197-mile exclusive economic zone, and the Great Lakes.

- Deep Seabed Mining Environmental Research Program ($0.4 million) -- Provides scientific information to predict potential adverse impacts from the mining of hard mineral resources in the deep ocean and to enable government decisions to be made regarding the mining of these resources in an environmentally sound manner.

- National Marine Sanctuaries Program ($0.5 million) -- Promotes and coordinates research to expand the scientific knowledge of marine sanctuaries and to improve management decision-making for the purpose of preserving or restoring their conservation, recreational, ecological, or aesthetic values.

- Ship Support ($1.9 million) -- Provides ship support for NOAA's marine pollution research and monitoring activities.

o Office of Oceanic and Atmospheric Research

- Environmental Research Laboratories Ocean Pollution Studies ($0.8 million) -- Conducts process-oriented research to improve our understanding of natural oceanic systems and the ecological impacts of human-induced stress on these systems; problem-oriented research is also conducted to develop improved assessment capabilities.

- Environmental Research Laboratories Great Lakes Pollution Studies ($2.3 million) -- Conducts process studies to improve our understanding and prediction of the impact of pollutants on the Great Lakes and problem-oriented research to develop improved engineering prediction models.

- Sea Grant Ocean Pollution Studies ($3.2 million) -- Provides funding to selected colleges and universities throughout the Nation to solve pollution problems related to state and local activities in fisheries, recreation, and overall resource management.

o National Marine Fisheries Service

- National Fishery Ecology Program ($3.3 million) -- Conducts research directed toward understanding the effects of man-induced and natural changes on the abundance, distribution, and health of living marine resources of commercial and recreational importance and their habitats.

- Microconstituents Program ($0.1 million) -- Conducts studies to determine the kinds and levels of contaminants in the tissues of fishery products of recreational, food, and industrial use.

o National Environmental Satellite, Data, and Information Service

- Marine Pollution Data Support Program (less than $0.1 million) -- Provides a variety of marine pollution data management-related activities, including data identification and acquisition, data processing and quality control, data and information products and services, and project data management support.

U.S. Department of Defense

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers (COE) has responsibility for conducting studies on the environmental effects of water use, water diversion, and construction projects in the marine environment. During FY 1988, COE funded $8.5 million for marine pollution research, development, and monitoring studies. The COE's marine pollution projects are divided into two major programs: the Environmental Quality Research and Development Program and the Navigation Project Environmental Operations and Maintenance Program.

- Environmental Quality Research and Development Program ($1.3 million) -- Concerned with the development of techniques and procedures for assessing, evaluating, and controlling the impact of COE and other coastal construction activities on the environment and the maintenance of national water quality standards.

- Navigation Project Environmental Operations and Maintenance Program ($7.3 million) -- Composed of the Long-Term Monitoring Project and the Long-Term Management Strategy Programs. The Long-Term Monitoring Project involves: the continued evaluation of nine existing habitat development field sites, low-cost breakwater tests to determine rapid development and survival benefits in marsh development and shoreline stabilization, and dissemination of information on beneficial uses of dredged materials. The principal objective of the Long-Term Management Strategy (LTMS) Program is to provide the field with protocols for developing LTMS's for disposing of dredged materials in an economically and environmentally sound manner.

The COE divisions and districts do not normally run research projects, but they do conduct all of the operation activities dealing with monitoring and data acquisition and interpretation as well as project-specific developmental research. These activities are carried out by the following regional division and district offices:

- North Atlantic
- New England
- South Atlantic
- North Central
- Lower Mississippi River
- Pacific Ocean
- South Pacific
- Southwest

U.S. Navy

The U.S. Navy expended $1.2 million on research, development, and monitoring programs related to marine pollution during FY 1988. The marine pollution programs of the Navy are carried out within the Environmental Protection Technology Program. The overall goal of the program is to develop pollution reduction, abatement, or treatment techniques and permit the Navy to meet present and future environmental regulations. The program involves the development of onboard systems for pollution source reduction and control and the investigation of environmental aspects of treatment technology. This includes establishment and maintenance of a data base on quality and generation rates of all shipboard wastes including expended ordnance. The remainder of the program addresses short- and long-term environmental effects of antifouling paints applied to ship hulls. This research includes investigations of the environmental fates and effects of synthetic organic compounds released from antifouling paints during drydock removal and routine service.

U.S. Department of Energy

The U.S. Department of Energy (DOE) plans and manages Federal energy programs. A major DOE objective is to carry out research and monitoring to ensure that energy programs are consistent with environmental legislation and policies. To fulfill these DOE objectives, a marine research program is conducted to gain an understanding of the effects of energy-related pollutants on the marine environment.

During FY 1988, DOE funded $5.8 million in research, development, and monitoring projects related to marine pollution. Current DOE marine pollution research is coordinated under the following programs:

- Regional Marine Program ($5.2 million) -- Supports research on natural physiochemical and biological processes to help determine the pathways and fates of energy-related materials in marine systems and food chains.

- Physiological Ecology Program ($0.6 million) -- Supports studies on genetics and physiology to determine limits of pollution exposure that will allow organisms and ecosystems to exist without adverse ecological perturbations.

U.S. Department of Health and Human Services

U.S. Food and Drug Administration

The U.S. Food and Drug Administration (FDA) is responsible for the safety of the Nation's foods, cosmetics, drugs, medical devices, biologics, and electronic radiological products. The FDA's Shellfish Sanitation Program, a cooperative Federal-State-industry activity, is the agency's only marine pollution-related program. Approximately $3.0 million was expended under this program during FY 1988 for marine pollution research, development, and monitoring. Under the Shellfish Sanitation Program, the agency's Bureau of Foods carries out regulatory and research activities to assure that shellfish are safe for human consumption. Research, technical assistance, and evaluations are performed on the effectiveness of sanitary practices in the growing, harvesting, processing, and marketing of shellfish.

National Institute of Environmental Health Sciences

The National Institute of Environmental Health Sciences (NIEHS) is responsible for the support of research in the areas of the effects of chemical and physical environmental agents on human health. This includes basic research as well as research on the causes of environmentally related diseases and how they develop. While the focus of NIEHS-supported research is primarily on human health, one of its programs supports ocean pollution-related research:

- o Extramural Program ($0.5 million) -- Supports research on the distribution and alteration of environmental compounds in the marine environment and their accumulation and biological effects in marine biota. Emphasis is placed on understanding known or toxic effects in the human population.

U.S. Department of the Interior

Minerals Management Service

The Minerals Management Service's (MMS) marine pollution-related research program supports one of the mandates of the Outer Continental Shelf (OCS) Lands Act Amendments of 1978, which is to provide for the protection of the human, marine, and coastal environments concomitant with mineral resource development on the OCS. To meet this goal and to meet information and administrative requirements of the National Environmental Policy Act of 1969, a nationwide OCS Environmental Studies Program was initiated by the Bureau of Land Management (now MMS) in 1974 to provide environmental information and analyses on marine and coastal ecosystems and to establish benchmark environmental conditions in all OCS areas for future identification of alterations caused by OCS activities. The program has since evolved from the benchmark environmental characterization approach to the monitoring of effects on marine ecosystems as oil and gas development occurs.

The OCS Environmental Studies Program is managed in the MMS Washington Office by the Branch of Environmental Studies located within the Offshore Environmental Assessments Division. Four MMS Regional Offices are responsible for managing environmental studies within their respective areas of jurisdiction. In FY 1988, MMS funded $18.0 million for marine pollution research and monitoring.

U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS) has general responsibility for perpetuating and providing public use and enjoyment of the fish and wildlife resources of the United States. Its functions include responsibility for the fish and wildlife resources and habitats of national interest through research, management, and provision of technical assistance to other Federal and nongovernment agencies and states. The FWS conducts operations in the entire coastal zone, the contiguous lands, and the waters that flow into the zone. Through the Assistant Secretary for Fish and Wildlife and Parks, FWS acts as the principal environmental advisor in reviewing various departmental policy and opinion documents for energy development programs, including those in the coastal zone. Portions of its component programs with marine pollution-related goals, objectives, and activities constitute important factors in the protection, conservation, and enhancement of estuarine and coastal fish and wildlife resources and their habitats.

The FWS funded $4.7 million for marine pollution-related research in FY 1988 under the Research and Development Program and the National Wetlands Inventory. The marine pollution-related research activities of these programs are presented below.

- o Research and Development Program ($2.9 million) -- Collects, collates, and interprets diverse information on fish species populations and habitats to provide information, methodology, and materials to assist fishery managers in decisions about the protection, enhancement, and utilization of fishery resources.

- o National Wetlands Inventory ($1.9 million) -- Prepares a wetland data base in map form, conducts a trends and analysis for wetland change, maintains standardized mapping procedures, correlates known wetland values, and upgrades and makes available the collected information.

U.S. Geological Survey

The U.S. Geological Survey (USGS) is responsible for the classification of public lands and examination of the geological structure, mineral resources, and products of the national domain. Over the years, the USGS's mission has expanded to include topographic mapping and hydrologic investigations of water in streams and underground. In compliance with its broad mission for earth science research and application, a few marine pollution-related programs are conducted by USGS.

In FY 1988, the USGS funded $2.8 million for marine pollution-related studies under two programs. These programs and their marine pollution-related responsibilities are presented below.

- o Water Resources Division Program ($2.0 million) -- Responsible for providing hydrologic data on surface and groundwater, including the long-term operation of downstream gauges on major rivers and streams (yielding both quantity and quality data) and site-specific investigations of estuarine circulation, geochemistry, and ecology.

- o Geologic Division Program ($0.8 million) -- Conducts research on the physical and geological processes on the seafloor.

U.S. Department of Transportation

U.S. Coast Guard

The U.S. Coast Guard funded $1.7 million for research, development, and monitoring projects related to marine pollution during FY 1988. The Coast Guard conducts environmental research and monitoring related to the effects of spills of polluting materials and other transportation-related pollution in the marine environment. The major program coordinating these activities is the Marine Environmental Response Program. The major goals and responsibilities of this program are as follows:

- o Marine Environmental Response Program ($1.7 million) -- Supports research on predicting behavior and movements of spilled oil and hazardous substances, as well as developing systems for more precise detection, sampling, identification, and quantification of discharged chemicals.

In addition, the Coast Guard is the United States' representative to the Intergovernmental Maritime Organization (IMO), which promotes improved safety and pollution prevention at sea.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) funded $31.7 million for research, development, and monitoring programs related to marine pollution during FY 1988. The EPA assumes lead responsibility in the Federal Government for identifying, evaluating, and controlling environmental pollutants. The purview of EPA includes freshwater, estuarine, coastal, and oceanic pollution. Marine pollution research activities range from specific mission-oriented endeavors to basic research concerned with achieving a general understanding of marine ecosystem structure and function. The major responsibilities of EPA include review of permits, setting standards, and overall regulatory activities. The EPA mandate includes the following areas of marine pollution research and monitoring:

- Marine Disposal Program ($6.0 million) -- Addresses the short- and long-term environmental effects of the disposal of municipal waste, industrial waste, and low-level radioactive waste in the marine environment.
- Energy-Related Research ($0.2 million) -- Includes environmental studies on the impacts of waste materials produced from offshore oil and gas drilling and production platforms.
- Water Quality Research ($8.3 million) -- Relates to establishing limits on substances, such as priority pollutants, toxic substances, pesticides, and carcinogens released into the marine environment.
- Great Lakes Research ($10.2 million) -- Addresses the pollution problems of the Great Lakes. Objectives include research on water quality and eutrophication and monitoring of contaminants and discharges from tributaries and point sources.
- Chesapeake Bay Program ($1.4 million) -- Coordinates pollution research in Chesapeake Bay. These efforts include research on sources, transport, fate, and physical properties of pollutants and on pollution control alternatives and data management.
- National Estuary Program ($5.1 million) -- Designed to develop a comprehensive master environmental plan to protect and restore water quality and living resources in the Nation's estuaries.
- Exploratory Research ($0.5 million) -- Involves long-term research conducted through cooperative agreements with universities. This research provides a link between basic and applied research on fates and effects of marine pollutants.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) does not have any direct statutory responsibilities for ocean pollution research, development, and monitoring, but does conduct studies indirectly related to marine pollution. Those projects indirectly related to the

National Marine Pollution Program fall under two categories. The first includes the development of space-borne techniques and the evaluation and application of these techniques to advance our understanding of the fundamental behavior of the oceans. These elements are conducted by the Earth Science and Applications Division of the Office of Space Science and Applications. The second includes programs that make possible the utilization of proven technologies and methodologies to other government agencies and industries for use in ongoing programs. These efforts are conducted by the Division of Technology Utilization in the Office of External Relations. The following describes the marine pollution-related activities conducted by NASA.

- Ocean Productivity Program ($0.5 million) -- Conducts research to improve the understanding of global oceanic primary productivity and phytoplankton distribution, reasons for observed spatial and temporal variability, how these distributions are influenced by ocean physics and circulation, and the impacts on living marine resources and global carbon and nitrogen cycles.

National Science Foundation

The National Science Foundation (NSF) funded $0.2 million for marine pollution-related research, development, and monitoring during FY 1988. The NSF has the mission to support scientific research to maintain and increase the Nation's ability to advance in scientific and technological areas. The NSF does not itself conduct research but provides funding for scientists in the public sector, mostly in academic institutions.

The Division of Ocean Sciences is the principal administrative unit within NSF that supports research relevant to marine pollution. Most of this research can be categorized as basic research, since it is not narrowly focused by mandates or policy. However, many of the findings from NSF-supported basic research make a contribution to other applied studies of marine pollution problems.

III. GOALS OF THE NATIONAL PROGRAM

The six goals of the National Marine Pollution Program are discussed in this chapter. These goals are designed to address the major polluting activities and pollutants of concern in the marine environment. The six goals of the National Program are:

Goal 1: Understand the Sources, Fates, and Effects of Toxic Materials Entering the Marine Environment as a Result of Human Activities

Goal 2: Understand the Sources, Fates, and Effects of Nutrients Entering the Marine Environment as a Result of Human Activities

Goal 3: Understand the Sources, Fates, and Effects on Marine Organisms of Biological Agents that are Introduced or Influenced by Human Activities

Goal 4: Understand the Effects of Losing or Modifying Marine Habitats as a Result of Human Activities

Goal 5: Document the Trends in the Status of Marine Ecosystems

Goal 6: Understand the Implications of Marine Pollution to Human Health

For each goal of the National Program, this chapter presents a discussion of the goal definition, Federal role in addressing the goal, management questions and information needs related to the goal, and conclusions and recommendations. Background information is presented under the goal definition discussion explaining what the problem is, why it is a problem, and where it is a problem. The legislation that mandates the Federal Government to address the goal and the Federal programs designed to study the problem are discussed in the Federal Role section. Under the management questions and information needs is a discussion of the rationale for addressing the management questions, the past and ongoing Federal activities that address the related information needs, and research and information gaps related to the information needs. Recommendations for future research, development, and monitoring activities related to each information need are presented in italic print.

GOAL 1: UNDERSTAND THE SOURCES, FATES, AND EFFECTS OF TOXIC MATERIALS ENTERING THE MARINE ENVIRONMENT AS A RESULT OF HUMAN ACTIVITIES

Nearshore and offshore areas of the marine environment in the United States have been degraded due to the input of toxic materials associated with human activities. Such inputs have resulted in the loss of important commercial and recreational fisheries due to mortality and a variety of sublethal effects. Toxic contamination of fishery resources has led to the closure of fisheries in several nearshore areas of the United States, including the closure of the striped bass fisheries in New York and Rhode Island and the closure of New Bedford Harbor to finfishing and shellfishing. For these reasons, understanding the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities is one of the six goals of the National Marine Pollution Program.

Goal Definition

Discharges and nonpoint source inputs of toxic materials into marine waters have resulted in elevated concentrations of these contaminants in the water column, sediments, and living marine resources in all regions of the country. This has raised concern as to the potential impacts of toxic materials to marine ecosystems and human health. Of particular concern are coastal and estuarine areas which serve as spawning and nursery grounds for many important commercial and recreational finfish and shellfish species. These are also the areas where the majority of pipeline discharges of wastes occur and which eventually receive toxic materials from nonpoint and upstream sources. For purposes of this chapter, toxics, toxicant, toxic agent, and toxic compound are defined according to Rand and Petrocelli (1984) as "...material capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death." Toxicity must be expressed in terms of concentration and duration of exposure (where possible) and in relation to a specific system in order to be meaningful to resource managers and others. Pathogens have been excluded from this discussion, but are addressed in another section of this Plan.

A variety of groups and agencies have identified individual chemicals or groups of compounds as potential problems when present in the marine environment. Of these compounds, some may be highly toxic while others, perhaps not quite so toxic, may still represent a high research priority if major information gaps exist with respect to their sources, fates, and effects. Table 3 is a list of pollutants that are known to have an impact on marine environments and that may require additional research. Compounds are presented by groups in the table since there is considerable overlap within each group in aspects of the sources, fates, and effects and, in several instances, their physical/chemical behaviors.

Toxic materials enter the marine environment directly by the intentional or unintentional release of wastes, either through dumping or pipeline discharges, and from nonpoint sources, such as rural and urban runoff and atmospheric deposition. Industrial and municipal plant discharges and nonpoint runoff into rivers that subsequently empty into estuaries and coastal waters can also contribute significantly to the pollution problems of these areas. Nationally, the largest quantities of toxic materials enter the marine environment from municipal and industrial pipeline discharges. Industrial discharges are the primary source of many organic chemicals and some metals (OTA, 1987); however, many other types of toxic materials are introduced from municipal point sources and nonpoint sources. The quantities of toxic materials in municipal effluents and sludges depend primarily on the nature of any industrial discharges to municipal treatment plants and the degree of treatment used. Rural and urban runoff are important contributors of toxic pollutants to marine waters in all parts of the country and often include large quantities of oil and grease, some metals, and pesticides (including chlorinated hydrocarbons). The atmosphere also plays a major role in the transport of some toxics into aquatic systems. Because of substantial reductions in PCB inputs from point sources, it is now estimated that over 50% of the PCBs entering the Great Lakes come from the atmosphere. PAHs, dioxins, other halogenated hydrocarbons, and metals such as lead, cadmium, and mercury also reach aquatic environments through the atmosphere (GLWQB, 1987; EPA, 1987; Crecelius, 1982; Yeats and Bewers, 1987).

The relative contribution of toxic materials to the environment from each of these sources varies from one region of the country to the next. Local and regional contributions from these sources are dependent on such factors as:

Table 3. Toxic Chemicals of Concern in Marine Environments

A. Halogenated compounds (excluding pesticides)
   1. Brominated dioxins
   2. Dioxins
   3. Hexachlorobenzene
   4. PCBs
   5. Trichlorobenzene
   6. Trichlorophenol

B. Polycyclic compounds
   1. Nitrogen-containing heterocyclic compounds
   2. PAHs (including benzofurans, benzopyrenes, phenanthrene)

C. Metals
   1. Alkylated lead
   2. Antimony
   3. Arsenic
   4. Cadmium
   5. Copper
   6. Mercury
   7. Selenium
   8. Tributyltin (and other organotins)

D. Pesticides
   1. DDT and metabolites
   2. Dieldrin
   3. Diflubenzuron (Dimilin)
   4. Methoxychlor
   5. Mirex
   6. Oxygen analogs of organophosphates
   7. Toxaphene
   8. Molting hormones

E. Others
   1. Azo compounds
   2. DEHP
   3. Diphenyl ethers
   4. Terphenyls

- o Type of industrial development;
- o Nature of industrial discharges to municipal sewage treatment plants;
- o Relative amounts of urban and agricultural runoff;
- o Extent of combined sewer overflows; and
- o Climatic factors (OTA, 1987).

High concentrations of toxic material in the marine environment have been identified as causing problems in all coastal regions of the country. Examples of the concentrations of DDT residues, aromatic hydrocarbons, and PCBs in the sediments of selected estuaries along the continental U.S. coast are presented in Figure 7. The nature, longevity, and severity of the impacts resulting from inputs of toxic materials varies among water bodies and is a reflection of the physical characteristics of the water body, the extent and types of disposal taking place, and the types and values of marine resources present (OTA, 1987). Some examples of severely impacted areas of the country, as evidenced by losses and changes of biomass, compromised fish health, or elevated levels of toxic substances, include Puget Sound, San Francisco Bay, and southern California on the west coast; portions of the Chesapeake Bay, Boston Harbor, New York Bight, Hudson-Raritan Estuary, and Buzzards Bay on the east coast; the Mississippi Sound and other areas in the northern Gulf of Mexico; and the Great Lakes.

Within Puget Sound, Elliott Bay has been identified as one of the most contaminated sites. Elevated concentrations of polynuclear aromatic hydrocarbons, PCBs, and some metals have been found in Elliott Bay sediments. Elevated concentrations of aromatic hydrocarbon metabolites in fish bile and PCBs in English sole livers were also found in the bay (McCain et al., 1988). Relatively high incidences of hepatic neoplasms in English sole and fin erosion in English sole and starry flounder have also been reported in Elliott Bay (Malins et al., 1984; Wellings et al., 1976; Malins et al., 1982; McCain et al., 1982; 1983). In San Francisco Bay, a variety of activities including municipal and industrial discharges have severely affected conditions in the bay. Organisms in the area have been exposed to elevated concentrations of metals, PCBs, DDT, and other toxic materials. Liver lesions (including neoplasms) have been detected in one or more fish species from the area. Evidence of impaired reproductive success in flatfish species related to pollutant exposure has also been obtained from studies conducted in the bay (McCain et al., 1988). In southern California, elevated concentrations of aromatic hydrocarbons and DDT have been detected in bottom sediments and in stomach contents and livers (for DDT derivatives) in fish, and are suspected of being responsible for various diseases (liver lesions and fin erosion) in fish in the area (Malins et al., 1986; 1987; 1988).

Toxic organic chemicals and metals enter the Chesapeake Bay from industrial and municipal pipelines and agricultural and urban runoff. Contamination of sediments and organisms by these pollutants is severe near Baltimore Harbor; other areas of the bay, such as the Elizabeth River in Virginia, also show evidence of contamination from toxic materials (EPA, 1983). PAHs were the most prominent organic contaminant detected in both the Maryland and Virginia portions of the bay. Elevated concentrations of PCBs and some trace metals have also been found in Baltimore Harbor sediments. Occurrences of lesions in fish have been correlated with concentrations of total PAHs in sediments of the bay (CBP, 1987). In Boston Harbor, high concentrations of environmental contaminants (aromatic hydrocarbons and PCBs) have been found in bottom sediments and in winter flounder (Zdanowicz et al., 1986). Murchelano and Wolke (1985) reported liver neoplasms in 8% of the winter flounder in

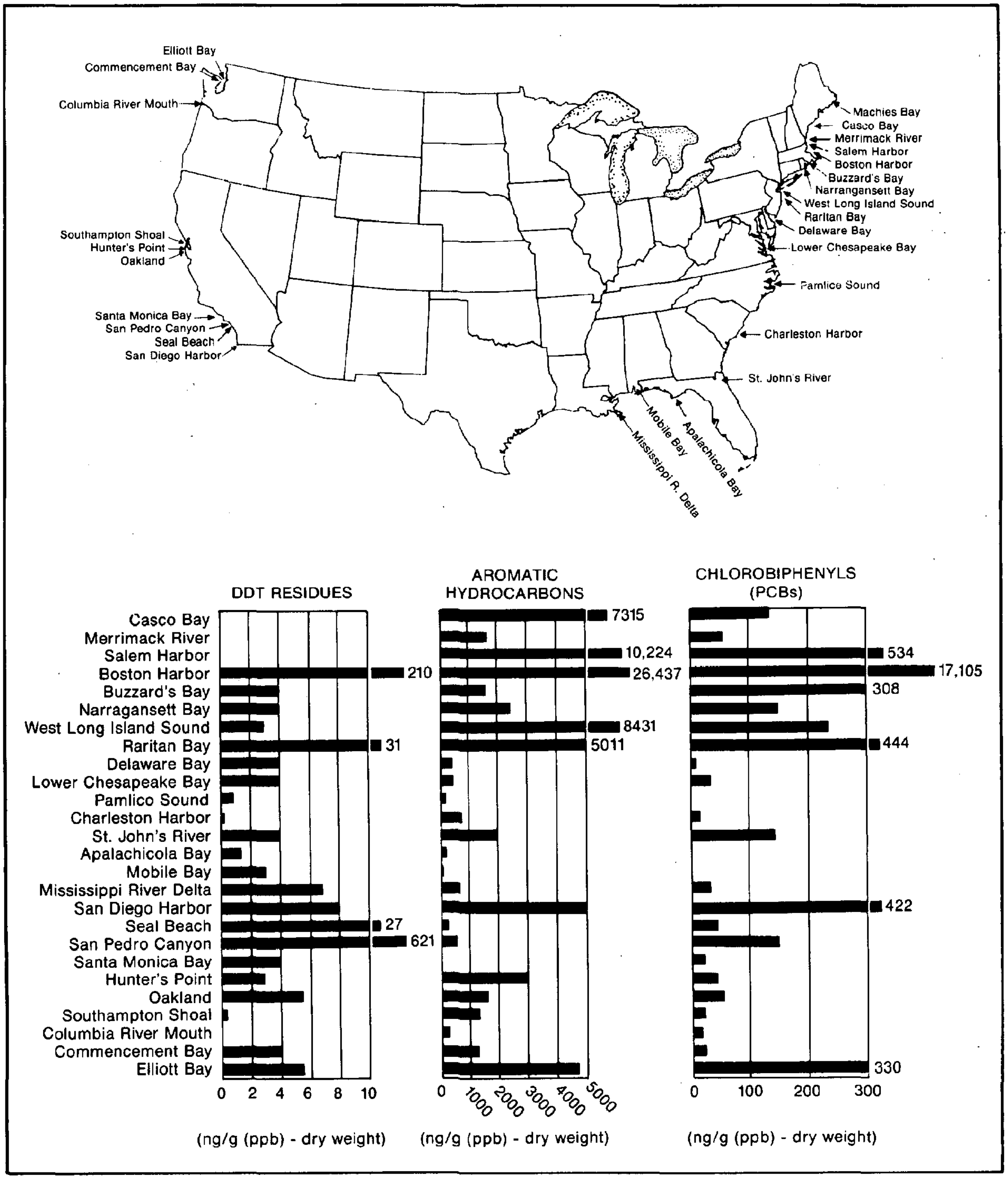

Figure 7. Concentrations of Toxic Materials in Estuarine Sediments (NOAA, 1984)

the area. A variety of chemical pollutants, including mercury, cadmium, PCBs, DDT and its metabolites, and petroleum hydrocarbons, has been found in elevated concentration in organisms, sediments, and waters of the New York Bight. High incidences of fin erosion, shell disease, and black gill disease have also been reported in fish and shellfish from the area (Murchelano, 1982). The Hudson-Raritan Estuary has been subject to serious industrial pollution problems during the past 100 years that have contributed to reduced diversity and abundance of living marine resources in the area. In addition, several commercially and recreationally important fisheries in the estuary have been closed due to chemical contamination of fish tissues (e.g., PCB and dioxin contamination) (Panel on Water Quality of the Hudson-Raritan Estuary, 1987). The New Bedford area of Buzzards Bay has been contaminated by a number of toxic chemicals, including PCBs, which has resulted in a high incidence of disease in lobsters and the closure of more than 18,000 acres of its coastal waters to fishing (EPA, 1986).

In the Mississippi Sound of the Gulf of Mexico, high levels of metals and organic chemicals have been found in the Pascagoula River and Biloxi Bay. Levels of chlorinated hydrocarbons have been identified as an especially significant problem in the area. Along other areas of the northern Gulf of Mexico coast, chlorinated hydrocarbons and other chemicals are introduced from the Mississippi and other rivers draining into the Gulf and from discharges associated primarily with refineries and the petrochemical industry. Dredging and disposal of contaminated sediments may release certain chemical constituents into the water column under certain conditions. The impacts of these discharges are usually localized but can be serious in highly developed areas such as Galveston Bay (Overstreet, 1987; King and Cromartie, 1986).

In the Great Lakes, persistent toxic substances have been identified as one of the major environmental issues confronting the region (GLWQB, 1987). Toxic pollutants of primary concern in one or more of the lakes include PCBs, DDT and metabolites, mirex, other organic chemicals, and some metals such as mercury and alkylated lead. Elevated concentrations of these contaminants have been found in the water, sediments, fish, and waterfowl.

Determining whether a toxic contaminant causes an adverse effect on living marine resources depends on the interaction of many chemical and biological factors, including bioavailability, concentration, length of exposure, and stage in the organism's life cycle. Determining the cause and effect relationships in marine biota can be difficult because changes can result not only from exposure to toxic materials, but also from natural perturbations, fishing, and other human-induced activities (OTA, 1987). Even when the presence of a toxic material shows evidence of a correlation with an impact, the ultimate source of the material may be unclear, and impacts may not be observed for years after exposure.

Impacts resulting from exposure to toxic materials have been documented in seabirds, marine mammals, and marine finfish and shellfish. Potential sublethal impacts of toxic materials on birds and marine mammals include indirect effects, such as altered habitats or food supplies, and direct effects from the ingestion of highly contaminated food, which has been reported to cause reproductive impairment in waterfowl and sea lions (OTA, 1987). If some toxic chemicals are present in sufficient concentrations, they can kill finfish and shellfish. One suspected cause of mortality in these instances is the crippling of the organism's nervous system. Sublethal impacts on finfish and shellfish include morphological, behavioral, physiological, and biochemical changes, and diseases. Fish exposed to elevated concentrations of some toxic materials have been shown to eat fewer or different organisms, be less active, and grow more slowly (OTA, 1987). A variety of behavioral changes, such as modifications of feeding behavior, burrowing activity, and tail flipping, have been reported as responses to toxics by the lobster Homarus americanus (Atema and Stein, 1974; Atema et al., 1979). Exposure to toxic chemicals has also been correlated with physiological impairment, immune deficiency, fin erosion, cataracts, ulcers, shell disease or erosion, tumors, internal lesions, and skeletal abnormalities. Finfish and shellfish species may also be less resistant to certain infections or suffer impaired reproduction. Some of these effects may eventually result in the organism's death (OTA, 1987). A summary of possible effects in the life cycle of a single species is shown for the winter flounder in Figure 8.

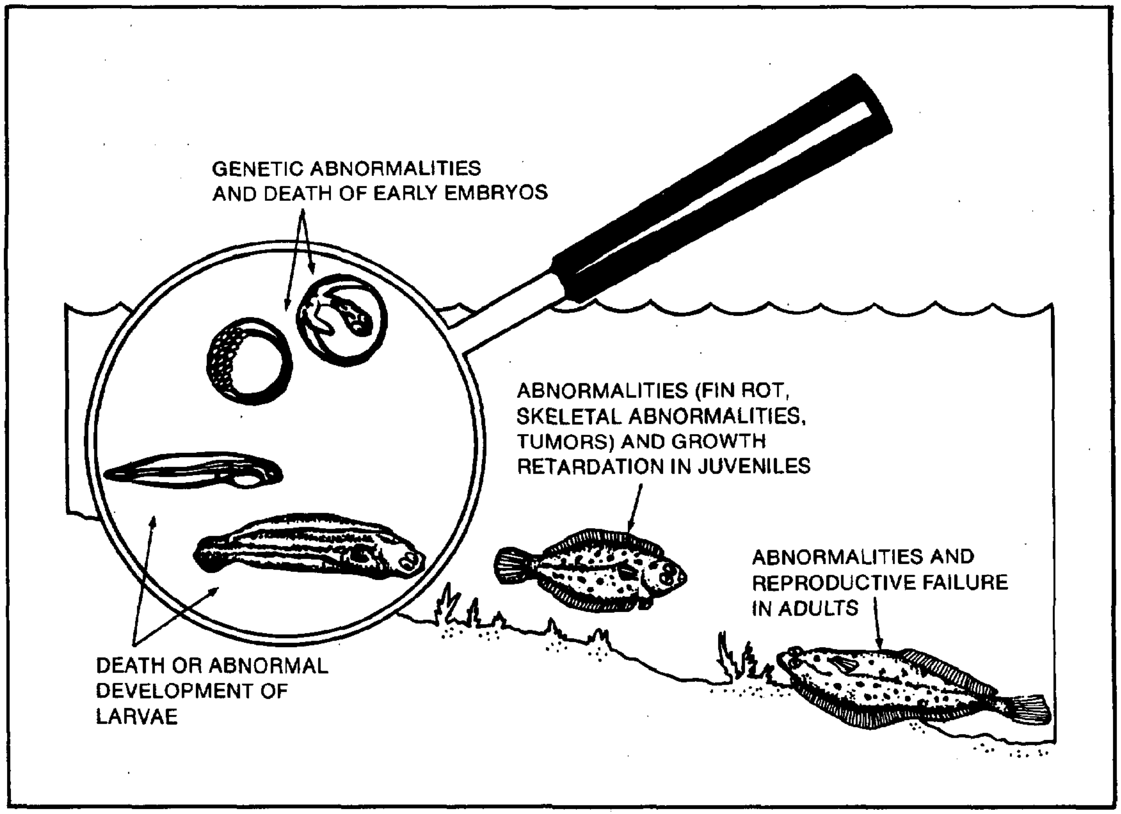

Figure 8. Some Possible Effects of Contaminants on Life Cycle Stages of the Winter Flounder (from Sindermann et al., 1980).

Probably the most important sublethal changes that result from exposure to toxicants are those that relate to an organism's growth and survival, thus its potential ability to contribute to the population gene pool (Capuzzo and Kester, 1987). These authors suggest that particularly sensitive responses that may cause population effects include biochemical responses that relate to energy metabolism and cell membrane function and those physiological responses that influence energy available for growth.

Federal and state pollution control programs have resulted in reductions of some pollutants in industrial and municipal discharges, and in many regions of the country the situation for some toxic contaminants has improved. However, due to the rapid urban and industrial growth that is occurring in many coastal areas of the country, the number of municipal and industrial dischargers is likely to increase. In addition, although direct discharges of some wastes through pipelines and dumping are coming under increased control, nonpoint sources of toxic chemicals through runoff and atmospheric deposition remain as serious problems.

Federal Role

This section discusses the Federal legislation, regulations, and programs that address the issue of sources, fates, and effects of toxic substances in the marine environment. Additional discussions of Federal programs related to specific information needs are presented in the management questions section, which follows this review of the Federal role. More detailed information on the Federal programs and projects that address the issue of toxic chemicals in the marine environment can be found in the National Marine Pollution Program, Summary of Federal Programs and Projects (NOAA, 1987).

Federal Legislation and Regulations

A number of Federal statutes address the problem of toxics in the marine environment. Those that are most relevant include the Federal Water Pollution Control Act, the Water Quality Act, the Coastal Zone Management Act, and the Marine Protection, Research, and Sanctuaries Act. These laws and their ensuing regulations are primarily directed towards prevention and control of toxics, resource management, and research and monitoring activities. Assignment of specific responsibilities to the various agencies within the Federal Government is expressed in each piece of legislation and is dependent upon the stated mission of the particular agency.

The Federal Water Pollution Control Act, also known as the Clean Water Act (CWA), establishes provisions for prevention and control of pollutants as well as for research and monitoring of toxics in the marine environment. The EPA is authorized to develop regulations designating which compounds are hazardous when discharged into waters and to issue permits for the discharge of municipal and industrial wastes when specified criteria are met. In addition, EPA is directed to set up a monitoring program to determine harmful effects of marine pollutants, and to establish field laboratories for the purpose of conducting research into the prevention, reduction, and elimination of pollution.

The Water Quality Act of 1986 amends the CWA and builds upon its established framework of compliance controls and research and monitoring programs. It establishes special treatment requirements for publicly owned treatment works (POTWs) and discontinues the permitting of discharges into the New York Bight Apex. The EPA is directed to set up research and monitoring stations, including a monitoring station off the California coast, designed to study the effects of sewage sludge on the marine environment. The CWA amendments also allow for the continuance of the Chesapeake Bay Program in order to determine the environmental quality of the bay, coordinate efforts to improve water quality, and to determine the impact of natural and manmade environmental changes on the resources of the bay. An estuarine management program is to be established for the purpose of developing comprehensive conservation and management plans which recommend priority corrective actions and compliance schedules addressing point and nonpoint sources of pollution.

The Coastal Zone Management Act (CZMA) authorizes the Federal Government to make grants to states for assistance in the development of a management program for water resources, as well as for the acquisition and development of estuarine sanctuaries. The CZMA also entrusts the Federal Government with establishing policy regarding the coastal zone.

The Marine Protection, Research, and Sanctuaries Act includes provisions for site designations, permit issuance, and research and monitoring. The Act provides for the initiation of a monitoring program to assess the effects of dumping in ocean and coastal waters and mandates a research program investigating the long-range effects of pollution on the ocean ecosystem.

Several other Federal statutes contain provisions relating to toxics in the marine environment. The Fish and Wildlife Coordination Act calls for investigations into the impact of domestic sewage sludge and other wastes on wildlife, including a determination of water quality standards for the maintenance of wildlife and an investigation into methods for pollution abatement. The Fishery Conservation and Management Act requires a comprehensive fishery research program, including an analysis of the impact of pollution on fish, wetlands, and estuarine degradation.

Federal Programs

A number of Federal agencies have missions that include understanding the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities. The National Oceanic and Atmospheric Administration (NOAA) under the U.S. Department of Commerce, and the Environmental Protection Agency (EPA) share the primary responsibility for monitoring and controlling toxics and the marine environment. Other Federal agencies with programs directed toward the abatement of toxic materials include the U.S. Department of Transportation, U.S. Department of the Interior, U.S. Department of Health and Human Services, U.S. Department of Energy, U.S. Department of Defense, U.S. Department of Agriculture, National Aeronautics and Space Administration, and National Science Foundation.

NOAA provides a focus to address the problems of the oceans and atmosphere in a unified manner. An important part of its mission is related to marine pollution and a balanced management of marine resources. Specifically, NOAA is charged with establishing a comprehensive ocean pollution research, development, and monitoring program and with ensuring that the results are disseminated in a timely manner and in a useful form to the Federal Government. NOAA also directs efforts toward the research of long-range effects of pollution. Its various program functions include living marine resources management and protection, which take into consideration the environmental impacts of resources and development activities and existing and potential ocean pollution conditions of living resources. NOAA also cooperates with other agencies such as EPA and FDA to achieve mission-related goals.

The EPA conducts a number of ocean pollution and Great Lakes research activities that include marine disposal research, energy-related research, and water quality research. Ocean pollution research is conducted at EPA labs at four locations across the country (Narragansett, Newport, Gulf Breeze, and Grosse Isle) and aboard two research vessels (Peter Anderson and Roger Simons). The EPA is responsible for regulating waste disposal activities including sewage sludge and industrial wastes, discharges through ocean outfalls, and ocean incineration. The EPA's water quality research establishes limits on specific substances found in the marine environment. Research is carried out on priority pollutants, toxic substances, and pesticides.

The Food and Drug Administration (FDA) of the U.S. Department of Health and Human Services conducts regulatory and research activities to assure that seafoods are safe for human consumption. The FDA and NOAA conduct considerable joint research under a Research Memorandum of Understanding, including research on metal contamination, and the FDA was a major participant in the recent study on PCB contamination of bluefish.

The U.S. Army Corps of Engineers, under the U.S. Department of Defense, monitors how the construction, operation, and maintenance of water resources projects impact on the environment and water quality standards. The Corps specifically monitors erosion rates and the long-term effects of dredging operations, including bioaccumulation and biomagnification.

The major research activity conducted by the U.S. Department of the Navy that relates to toxics in the marine environment centers on the environmental and health effects of hull antifouling systems. The Navy is currently researching the development of a system to detoxify organotin hull coatings and paint removal debris. The research includes studies of short- and long-term environmental effects of organotin compounds.

The Effects of Agricultural Practices Program under the U.S. Department of Agriculture (USDA) investigates pollution problems caused by soil erosion; agricultural runoff; agricultural waste disposal; offsite and downstream effects of sediment, nutrients, and pesticides; transport and transformation of pollutants; and effects on organisms and ecosystems. The USDA funds research contracts and grants through cooperation with states and universities. The Department is currently sponsoring research investigating diurnal and seasonal patterns in streams channelized to promote drainage to improve agricultural production. The research is specifically looking at copper, iron, lead, and other metals that may be applicable to estuarine pollution.

The National Institute of Environmental Health Sciences (NIEHS), under the U.S. Department of Health and Human Services, supports marine pollution related research, including studies of aquatic organisms from polluted waters as early indicators of pollution and studies using aquatic organisms as experimental models for specific diseases.

Several other agencies maintain programs that are related to toxics in the marine environment. For example, the U.S. Department of the Interior is charged with protecting marine organisms while developing mineral resources. The U.S. Department of Transportation through the U.S. Coast Guard focuses on reducing the potential for pollution and ensures that effective countermeasures and cleanup operations are conducted for accidental discharges.

Management Questions and Information Needs

Toxicants introduced into the marine environment enter biogeochemical cycles in operation within the environment and can adversely affect living resources. There are linkages among sources of toxicants, their transport through the system, and their ultimate fate to potential toxic effects within and on the system. Movement, fate, and effects of toxicants in marine ecosystems can be complex because, as toxicants move through the systems, they can impact the biota and adversely alter the system. Conversely, the "system" can alter toxicants through physicochemical and biological actions and render the toxicant more or less toxic. For example, some metals can be methylated, which results in a more toxic form, and some organics can be dechlorinated, which results in a less toxic form.

Sources of toxic materials to marine ecosystems include rivers and streams, shoreline erosion, point and nonpoint sources, and atmospheric deposition. We probably know the most about materials entering from rivers and streams (through NPDES and other regulatory mechanisms), and the least about atmospheric deposition. For this reason, atmospheric sources are discussed in some detail under Management Question 1.

The transport and fate of toxicants in marine ecosystems are dependent upon factors including biological, chemical, and physical characteristics of the toxicant and the ecosystem. For example, a nonpolar organic toxicant may be readily adsorbed onto particulate and detrital matter, and chelated or complexed metals may be more readily adsorbed than other metal species. Toxicants adsorbed onto deep-layered sediments may become more available for exchange and bioaccumulation when the sediment is resuspended by bioturbation or episodic events such as storm surges that scour the bottom.

If one is to predict the impact of a toxicant on marine resources, it is necessary to know as much as possible about the routes by which the toxicant moves through the system, the rates at which it moves, the reservoirs and residence times in them, the transformations of the toxicant, as well as the toxicity of the toxicant to the system or components of the system. Thus, it is important to discuss the sources and loading rates of toxicants, the mechanisms that control their transport and availability, and their effects on organisms and populations.

The management questions and information needs discussed in this section focus on these most important aspects of toxic substances in the marine environment. The three management questions listed below represented management information needs related to the goal of understanding the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities.

Management Question 1: What are the sources and loading rates of toxic contaminants in the marine environment?

Management Question 2: What are the mechanisms that influence exposure patterns and bioavailability of toxic contaminants in the marine environment?

Management Question 3: What are the effects of toxic contaminants on marine organisms and populations?

This section will include a discussion of the rationale, current efforts, and additional work associated with the information needs for each management question.

Sources and Loading Rates

Management Question 1: What are the sources and loading rates of toxic contaminants in the marine environment?

Information Needs

1a. What is the relative contribution of toxic substances to the marine environment from the atmosphere?

1b. What is the relative significance of seasonal activities and storm events in toxic substance loadings?

1a. What is the relative contribution of toxic substances to the marine environment from the atmosphere?

To develop mass budgets of toxicants entering the environment, we have become increasingly aware of the role of the atmosphere in transport of contaminants to the marine environment. An overall management program for toxic materials in the marine environment must include an evaluation of this source because it can be a predominant transport mechanism for some toxic material in some areas.

The atmosphere can be a significant source of PAHs, PCBs, some metals such as lead, zinc, mercury, and cadmium, as well as other toxic substances in aquatic systems (EPA, 1987; GLWQB, 1987; Crecelius, 1982). Atmospheric deposition of some metals has been estimated for the Chesapeake Bay (Bieri et al., 1982) and Delaware Bay (Church et al., 1984). While measured atmospheric loadings for these metals were not large compared to other sources, they were significant, especially in remote areas away from industry and other concentrated sources. In some coastal areas, such as the Southern California Bight, measurements show that up to one-half of the PAHs and particulate metals entering the water came from direct atmospheric deposition. In studies of the New York Bight, mussels and polychaetes appeared to contain a hydrocarbon distribution much more indicative of spilled petroleum origin, while the sediment contained a mixture of petroleum and pyrogenic source PAHs which may have been transported via the atmosphere (Wakeham and Farrington, 1980; NRC, 1985). In the Great Lakes, it has been estimated that greater than 50% of the loading of PCBs to the lakes occurs through the atmosphere (GLWQB, 1987). The atmosphere may also be a significant source of other toxic materials to the Great Lakes, such as metals (lead, mercury, cadmium, and arsenic) and PAHs.

Atmospheric inputs of toxic chemicals are even more significant in open ocean areas that are far away from point source discharges and runoff to coastal waters. The significance of atmospheric inputs of lead to the surface waters of the oceans is shown in profiles for lead in the Atlantic and Pacific Oceans (Schaule and Patterson, 1983). A larger industrial lead input via the atmosphere results in surface water lead values in the Atlantic that are two to three times higher than in the Pacific. Crecelius (1982) estimated that 96% of the lead in the surface 0-100 meters of the open ocean area is transported via the atmosphere, whereas only about 10% of the chromium and nickel delivered to the oceans are carried by the atmosphere. Yeats and Bewers (1987) estimate that one-third of dissolved cadmium delivered to the oceans is transported via the atmosphere; the remaining two-thirds is carried by rivers. Overall, these authors estimate that about 10% of the total cadmium transport to the oceans (particulate plus dissolved) is via the atmosphere; however, they state that the "...literature is replete with measurements of cadmium in atmospheric precipitation."

Current Federal activities addressing the issue of atmospheric deposition of toxic substances to the marine environment are being conducted by EPA, NOAA, and the National Science Foundation (NSF). The EPA Great Lakes Research Office developed GLAD (Great Lakes Atmospheric Deposition Network), a program to determine the loading of metals and nutrients from the atmosphere to the Great Lakes. Samples were also analyzed for trace organics such as PAHs, halogenated hydrocarbons, and organophosphate pesticides. Included in the program is the development of a sampler capable of collecting atmospheric precipitation samples throughout the year. NOAA has supported two programs evaluating atmospheric transport in Wisconsin to determine the volatilization of PAHs and halogenated hydrocarbons to Green Bay. One program is an evaluation of the persistence of these toxics within an aqueous system, while the other is the development of an overall fate assessment model which includes volatilization. Another study supported by NOAA estimated the volatilities of indosulfan, fenvalonite, and other pesticides commonly used in South Carolina. NOAA, under the Marine Ecosystems Analysis New York Bight Project, also supported research investigating major nonpoint source contributions, including atmospheric inputs, to the New York Bight. The NSF funded research related to atmospheric deposition in remote areas of the Pacific Ocean through the SEAREX (Sea-Air Exchange) project.

Up to this point, Federal programs directly addressing atmospheric transport have focused primarily on freshwater (Great Lakes) systems, and this work is far from complete. These efforts should continue until sufficient data are collected and the models are fully developed and verified. Similar programs for the marine environment are needed and should be initiated in several major estuaries. There has yet to be a well-constrained study of the relative amounts of some toxic contaminants, such as PAH, contributed to coastal and open ocean waters of the United States by riverine inputs, sewage effluents, atmospheric inputs, and other sources (Farrington, 1988). If one were to model the overall fate of toxicants in aquatic systems and develop appropriate abatement procedures, further information on the relative contribution of toxics via the atmosphere and a better understanding of the processes involved would be needed.

The collection of additional monitoring data will help quantify atmospheric inputs. Sediment profiles on the continental shelf should be examined for the relative contributions of atmospheric (combustion-derived) and petroleum-derived PAHs. In addition to differences in the chemical fingerprints of the toxicants, carefully chosen transect stations will help to discriminate sources. Direct measurements of PAHs, halogenated hydrocarbons, and cadmium, mercury, and lead should be made in surface seawater and in air samples taken over the ocean downwind from industrial and urban centers and at remote sites to help separate large-scale (global or continental) contaminant problems from local sources. Measurements of stable lead isotopes in surface seawater should be made to help fingerprint sources. Measurements should also be taken in the sea surface microlayer.

1b. What is the relative significance of seasonal activities and storm events in toxic substance loading?

Agricultural applications of pesticides are practiced intensively during the spring and summer months, coincident with the spawning and early life growth of many marine species. A number of important resource species such as striped bass, shad, and salmon move up estuaries to brackish and freshwater areas to spawn. The proximity of these smaller streams to agricultural lands maximizes the exposure of adults and, more importantly, the more sensitive eggs and larvae to pesticides in runoff. In addition, excessive runoff due to the spring thaw tends to bring higher surficial sediment loads with adsorbed toxics from both urban and nonurban sources into the marine environment at critical times.

Frequently, mass balance budgets are calculated on an annual basis and loading models that predict the routes, rates, and reservoirs of chemicals in the marine environment do not account for episodic events. Yet it is known that such events can cause great fluctuations in the transport of water and suspended particulates and thereby alter salinity and turbidity, factors directly and indirectly affecting marine organisms. For example, a resurgence in DDT levels in the livers of sea trout from the Texas Gulf Coast was attributed to a storm event that resuspended DDT-laden sediment and other particulate matter and made the chemical more available through the food web to the trout (Butler, 1988). The transport of dissolved and particulate trace metals from the Mississippi River to the Gulf of Mexico is greatly influenced by seasonal events as well as by long-term practices (Trefry et al., 1985; 1986). Total transport of lead and other potentially toxic metals by the Mississippi River is greatest during the high suspended-sediment events of the spring melt. However, highest dissolved lead and other trace metal levels are frequently observed during the low-flow, summer period. A study was conducted of annual suspended-sediment discharges of three U.S. rivers (Juniata River at Newport, Pennsylvania; Delaware River at Trenton, New Jersey; and Eel River at Scotia, California) to determine the effects of large storm events on suspended sediment loads (Meade and Parker, 1985). Investigators demonstrated that nearly one-half of a year's sediment (and associated contaminants) is usually discharged in 3.65 days, and nearly 90% usually is discharged in 36.5 days.

Federal programs addressing the issue of seasonal activities and episodic events are being conducted under NOAA and the U.S. Department of Agriculture (USDA). NOAA supports a program to evaluate pesticides in storm runoff to Lake Erie. The USDA is involved in studies to model the fate of agricultural chemicals in freshwater and marine systems. These types of programs could be expanded to include the Chesapeake Bay, Delaware Bay, the Hudson River estuary, and other major estuaries that are known to provide spawning and nursery areas. A coordinated program to evaluate loading rates and the timing of these with respect to biological activity would provide the most valuable information.

Some gaps in our knowledge of seasonal and episodic events include lack of information on life-histories of estuarine organisms for specific areas, knowledge of pesticide application patterns, and the frequency and severity of past episodic events for specific marine areas. Of particular importance is the effectiveness of differing agricultural practices in reducing the amounts of nutrients and toxics in runoff entering aquatic systems. A variety of approaches could be beneficial, such as the use of riparian zones and chopping and burning for site preparation instead of shearing and winnowing to minimize erosion. Streams can be marked before spraying and avoided, or at least a strip on either side of each stream left unsprayed. Wet weather can be avoided when chemicals are applied. Comparative data on the effectiveness of these methods would be useful.

Pilot studies involving regional monitoring programs would improve our understanding of seasonal phenomena and storms. For example, selected streams in the drainage system of a major estuary could be monitored more frequently and the mass loading rates of organic chemicals under normal and storm conditions compared. A subset of this study would be to compare areas where different agricultural practices are used. The National Marine Fisheries Service (NOAA) has reliable information on the timing and nature of spawning habits of most resource species. Toxicity data on the chemicals could then be factored into an overall assessment model to evaluate risk to marine species. The goal of the assessment is to determine whether changes in application practices or the timing of application could make a significant difference in protecting marine resources. More information on seasonal patterns of particulate and dissolved trace metals as well as the chemical speciation of dissolved metals as a function of salinity, organic matter, and suspended-sediment concentration would also contribute to our understanding of this area.

Transport and Bioavailability

<u>Management Question 2: What are the mechanisms that influence exposure patterns and bioavailability of toxic contaminants in the marine environment?</u>

Information Needs

2a. What factors influence the transport and physical fate of toxic contaminants in the marine environment?

2b. How do the physico-chemical forms of toxicants affect bioavailability?

2c. How do metabolic processes affect uptake and toxicity of contaminants?

<u>2a. What factors influence the transport and physical fate of toxic contaminants in the marine environment?</u>

The transport and physical fate of toxic contaminants is a function of their physico-chemical form and their particle- or biological-reactivity in seawater. Many contaminants of biological concern, such as PAHs, PCBs, halogenated hydrocarbons, and some trace metals, are very particulate-reactive and are frequently associated with particulate matter. The transport of particulate-reactive contaminants within coastal areas usually coincides with sediment transport processes.

Fine-grained particles, such as montmorillonite clays, provide effective surfaces for adsorption of material from seawater. Most of the organic contaminants, such as PAHs, have low solubilities in water and readily adsorb to particulate matter. However, dissolved organic matter has been postulated to increase the solubility of PAHs in seawater (Boehm and Quinn, 1973). In addition, changes in pH and salinity have been shown to alter the adsorption and availability of organic toxics. It is possible to predict the partitioning behavior of many nonpolar compounds, including some PAHs, on a range of sorbants if either the compound's water solubility or the sorbant's organic content is known (Karickhoff et al., 1979; Means et al., 1979).

The physical fate of trace metals in seawater is directly related to their particle- or biological-reactivity. Metals such as lead, iron, and thorium are rapidly removed from seawater by particles (Salomons and Forstner, 1984). In contrast, the distribution of cadmium, zinc, copper, and nickel are linked to nutrient cycles and are controlled by biological processes (Bruland, 1980).

The transfer of toxic materials to marine biota and man and their effect on ecological systems are often dependent on the availability and persistence of toxicants within sediments and transport within benthic ecosystems (Capuzzo and McElroy, 1987). There are many examples of the accumulation of contaminants from sediment. Recently, NOAA's Status and Trends Program reported a statistically significant relationship between the DDT concentration in Atlantic croaker livers and the concentration in sediment (NOAA, 1986). These data demonstrate only evidence of a relationship and do not show that the concentrations in the liver were a result of concentrations in the sediment.

Analytical tests can reveal the presence of contaminants, but these tests do not reveal the kinetics of sorption/desorption rates that are necessary to model and predict movement. Thus, it would be useful to understand and quantify the processes that control the routes, rates, and reservoirs of various contaminants released into the marine environment. Mechanisms of resuspension and deposition would need to be determined because these factors influence availability and thus toxicity of contaminants. Knowledge of the kinetics of sorption/desorption is basic to understanding the movement and effects of toxicants in the marine environment.

Significant advances have been made during the last decade in studies of trace metals in the marine environment (e.g., Bruland, 1980; Yeats and Bewers, 1987). However, we still do not have adequate techniques to address the following: partitioning of trace metals between dissolved and particulate forms, chemical speciation of selected trace metals in seawater, and kinetics of regeneration of trace metals in bottom waters or release from sediments.

2b. How do the physico-chemical forms of toxicants affect bioavailability?

Toxic contaminants entering the marine environment can be adsorbed onto sediments and particulate matter, remain in the water column or volatilize, or be accumulated by the biota. Their fate depends to a great degree upon the physical/chemical state of the contaminant. For example, Lee (1984) points out that the level to which a compound is accumulated by the biota is related to the hydrophobic properties of the compound (octanol-water partition coefficient). Most risk assessments of the impact of toxicants on marine organisms require knowledge of the fate and bioavailability of the toxicant. Models can be developed to predict the fate of certain toxicants, and a fundamental requirement in the development of fate models is knowledge of the basic physical chemistry of the compounds in question, i.e., solubility in water; vapor pressure; and partitioning between air and water, soil and water, and soil and runoff. Toxic chemicals are exposed to a wide range of environmental conditions from their source to their eventual fate in the marine environment. In addition to changes between phases, such as from soil to air to water to sediment, there are wide variations in parameters such as temperature, pH, salinity, and turbidity. These factors affect both the partition coefficient and the bioavailability of toxic material.

Numerous laboratory studies have shown that aquatic organisms can accumulate PAHs, PCBs, and halogenated hydrocarbons from the water column, sediments, and their diets (e.g., Neff, 1979). However, it is also clear from these studies that the bioavailability of toxic material from different sources is not equivalent. It is not sufficient to know the quantity of a contaminant in the marine environment. Proper management also requires an understanding of the form of the chemical and whether it is bioavailable.

Accumulation of dissolved PAHs has been well documented in many species, with bioconcentration factors ranging up to 10,000. However, the relative availability of PAHs from the various sources is not clear. It may be that PAHs sorbed to sediments are only available to organisms after undergoing desorption into the dissolved phase (McElroy et al., 1986). However, there will always be a dynamic exchange between PAHs in the solid and dissolved phase. Altering the concentration in either phase (e.g., by uptake) will initiate redistribution of the PAHs between phases. The presence of organic matter in the water often presents a third phase, colloids, whose influence is not easily measured.

The influence of colloidal organic matter in interstitial waters of natural sediments has only recently begun to be investigated. Results of investigations on the influence of interstitial colloids on partitioning of polychlorinated biphenyls (PCBs), similar in many properties to PAHs, have shown that observed distributions of most PCBs in pore waters were consistent with a three-phase, solution-colloid-solid, equilibrium partitioning model (Brownawell and Farrington, 1985; 1986).

The equilibrium concentrations of a toxicant in any two phases, soil/air, air/water, water/sediment, sediment/interstitial water, can be expressed in terms of partition coefficients (Leo et al., 1971; Means et al., 1979). Only a few of these partition coefficients have been determined. Since it is virtually impossible to monitor the constantly changing concentrations of a toxicant in various phases, partition coefficients for the appropriate phases of problem contaminants should be determined. It should then be possible to monitor the concentration of the chemical in a few key phases, and thus assess potential problems with bioaccumulation.

The bioavailability of trace metals is governed primarily by their chemical form. Ray and McLeese (1987) modeled the biological cycling of cadmium by considering three reservoirs of available cadmium: water, suspended particles (including plankton), and sediments. However, bioavailability is clearly not related to total metal loading in any of these reservoirs. It is generally agreed that the ionic form of cadmium in seawater is most bioavailable (Ray and McLeese, 1987); however, we still have inadequate direct measurements on the speciation of potentially toxic metals in seawater.

Seasonal variation is a major factor in metals concentration data. Data from Narragansett Bay for the period 1975 to 1978 for a single station (monthly samples) showed 2- to 4-fold differences in the metals concentrations. In a review of historical metals data for the New England region, Capuzzo and McElroy (1987) concluded that no long-term temporal trends were definable from the combined data because of changes in methodology, irregular sampling on both temporal and spatial scales, and analytical differences.

Certain biological compartments such as surface microlayers, sediment-water interfaces, pore waters, and plant root-water-sediment microenvironments (i.e., roots of Thallasia testudinum) can be especially important in relation to bioavailability of pollutants because it appears that pollutants can concentrate in these compartments. There is a need to develop new and innovative methods to measure residues of toxic contaminants in such *microenvironments, particularly at the parts per billion (ppb) and parts per trillion (ppt) levels. High-resolution techniques are necessary for these areas of the water column and sediments because of the typically high concentrations of toxicants found there and their importance to sensitive life history stages of many organisms.*

Research on the physical chemistry of toxic material with respect to bioaccumulation is in a very early stage and is quite incomplete. There are many toxicants about which very little is known in this regard, and fundamental information is lacking for some of the more common chemicals. Programs currently established to evaluate toxic materials in the marine environment should include basic physical chemistry, especially the interaction of toxicants with seawater and particulate organics. The use of partition coefficients to build models of toxicant fate should be expanded and these models should address partitioning under various environmental conditions. Because of the large number of problem contaminants, individual compounds that are known to be primary causes of toxicity in the marine environment should be studied first. Overall fate models should be developed with the appropriate physical/chemical determinations made where necessary.

2c. How do metabolic processes affect uptake and toxicity of contaminants?

Chemical compounds introduced into marine ecosystems become part of the biogeochemical cycles in operation within the systems and can affect the biota. Recently, emphasis has been placed on the fact that biological activity can significantly affect the structure of the chemical compounds. Biotransformations, biologically catalyzed conversions of one chemical to another, can play a significant role in the bioaccumulation and toxicity of chemicals, and this transformation should be differentiated from purely physical/chemical processes (Lech and Vodicnik, 1984). Enzymes are the biological catalyst for biotransformations, and these transformations can make a compound more soluble, thus possibly more readily excreted by organisms. However, metabolism by microorganisms could alter the solubility of compounds in the environment, affecting the associations with particles, hence availability. From an ecosystem perspective, biotransformations profoundly affect the fate and availability of chemicals in the system. Unfortunately, the rates and products of biotransformations are presently defined for relatively few chemicals, primarily a limited number of aromatic hydrocarbons.

The transformation of chemicals has been studied in tissue preparations and in intact marine organisms. Enzymes present in the tissues of most types of organisms catalyze the transformation of organic chemicals. This transformation is often initiated by oxidative enzymes, termed monoxygenases, that incorporate molecular oxygen into the compound, thereby changing its structure and its biological activity. This process is central to the accumulation and the toxicity of organic toxicants.

Two important groups of monoxygenases are the flavoprotein monoxygenases and the cytochrome P-450 monoxygenases. In marine systems the cytochrome P-450 system is better known. Cytochrome P-450 is known to initiate the transformation of many aromatic hydrocarbons, with some products that are toxic or mutagenic. Cytochrome P-450 systems have been reviewed by James and Bend (1980), Stegeman (1981), and Stegeman and Kloepper-Sams (1987).

Enzyme systems such as the cytochrome P-450 dependent mixed-function oxidase (MFO) system are responsible for initiating metabolism and detoxification of many organic contaminants including pesticides and PAHs. The system detoxifies some contaminants' reactive toxic metabolites. The mutagenic potential of PAH is known to arise only after metabolic activation (Sims and Grover, 1974; Jerina and Daley, 1974). Additional information on the mechanisms of toxic action to various species is needed to evaluate the effects on marine species and possible human health risk through consumption of contaminated species, especially those containing mutagenic metabolites. Different groups of animals have different capacities for metabolism of organic and metallic compounds, which can affect the accumulation of these compounds in the organisms. Bivalves appear to have little capacity to metabolize PAHs and, therefore, accumulate them rapidly. In one instance, when fish and bivalves occupied the same contaminated area, concentrations of PAHs were lower in fish than in the bivalves.

Organisms also have mechanisms for detoxifying metals. Metallothioneins are cysteine-rich proteins that can bind metals, primarily copper, cadmium, zinc, and mercury. Exposure to metals induces the synthesis of these proteins, which have a finite capacity for metal-binding. When this capacity is exceeded, toxicity can result.

Pharmacokinetic models are often used as tools to study metabolic processes and how transformed chemicals are bioaccumulated. The kinetics of uptake and release of lipophilic organic contaminants and the relationship between body burdens and environmental concentrations have generally been described by simple (one-compartment) pharmacokinetic models, where partitioning between the environment and the organism is assumed to be steady state and the organisms are considered to be a single, homogenous unit (O'Connor and Pizza, 1987). The simple models generally assume that uptake is from the water only and that all residues belong to a common pool. But residue dynamics are much more complicated than this simple model entails, and empirical data often deviate from predicted values. Certain tissue levels may in fact be increasing while overall body burdens are declining (O'Connor and Pizza 1987). In addition, while some studies have shown that an apparent equilibrium concentration of a toxic material in tissues may be achieved fairly rapidly (24 to 48 hours), recent studies show that total uptake of contaminants continues to increase over longer periods (months) of exposure.

Bioconcentration patterns appear to be influenced by chemical properties of specific toxic compounds. This is reflected in differing uptake potential of various tissues and varying distributions of contaminants among different tissues (Widdows et al., 1982; Neff, 1979; Chiow, 1985; Farrington et al., 1986). These factors can result in differing rates of uptake and depuration in various tissues within the same organism.

O'Connor and Pizza (1987) suggested that no published data support the hypothesis that PCBs accumulated by fishes are metabolized by or eliminated from tissues with rate constants directly comparable to values determined for the whole body compartment. Their experimental results suggest that this is not the case. Bioconcentration in marine animals, therefore, may best be explained through the use of multicompartment models in which distribution between different body compartments is considered and bioconcentration is dependent on relative rates of uptake and exchange of toxics between body compartments.

Microbial transformations can convert some toxic chemicals into even more toxic materials or might make material that is more bioavailable less toxic. Microorganisms such as bacteria and fungi can utilize different carbon sources and can oxidize some aromatic hydrocarbons completely to carbon dioxide and water and utilize hydrocarbons as a source of energy. Thus, microorganisms can transform chemical compounds found in sediment, water, and biota. Many studies have documented this capacity to transform chemicals in the marine environment. For example, microbial action in one of three types of sediment presumably biotransformed 100% of added trichloroethane (TCE) to cis-1,2 dichloroethane in 24 months (Barrio-Lange et al., 1987). Reductive dechlorination of TCE occurred in another study where residues of polychlorinated biphenyls in sediment and fish from the Hudson River and other locations showed changes in gas chromatographic peak distribution indicative of reductive dechlorination (Brown et al., 1987). It appears that several different populations of anaerobic bacteria dechlorinated with their own distinctive pattern of PCB congener selectivity. The apparent capacity of bacterial action to dechlorinate PCBs has ecological ramifications because PCBs in sediments normally are not exposed to solar radiation, and thus are not subject to dechlorination by photolysis, the only previously documented transformation process. Also, bacteria can transform metal species through methylation, which often results in a more readily available compound such as the methylations of mercury to methyl mercury. It is this form of the metal that is especially toxic to marine life as well as a hazard to human consumers of seafood products.

Gaps in our knowledge about the relationships between biotransformation products, bioaccumulation, and the models to study these processes include a need for more information on identity, distribution, and rates of formation of biotransformation reaction products (particularly microbial transformations) as well as the toxicity of these products. To date, most biotransformation studies have been conducted <u>in vitro</u>; however, these reactions may or may not take place to the same extent in whole or intact organisms. Yet, data on identity of metabolites in bile suggest that <u>in vitro</u> metabolites are also formed <u>in vivo</u>. Additional research on reactive product metabolites, particularly how potential mutagen and carcinogen products are accumulated by marine organisms would improve our understanding in this area. This latter need could be addressed through studies to evaluate the presence of metabolites bound to DNA and/or protein.

Also, a lack of analysis of biotransformation products in most monitoring studies can result in erroneous conclusions. For example, residue data from a malathion (organophosphate pesticide) uptake study showed that neither malathion or its oxidative product, malaoxon, were detected, but the hydrolysis products malathion mono- and dicarboxyhic acids did appear (Cook and Moore, 1976). Most monitoring programs would not have detected these transformed hydrolysis products.

The use of multicompartment models for studies of transformation and bioaccumulation is in the early stages of development. Research efforts on other organic contaminants and a variety of commercially important species would be useful. Most of the work to date has been based on short-term studies in which equilibria are presumed to occur within 24 to 48 hours. New studies should include long-term evaluation of uptake and release of problem toxic compounds to more properly reflect actual environmental exposure. Also, to assess the full consequences of exposure of marine organisms to toxic compounds, the multicompartment model approach should include studies on the fate of toxicants in critical tissues (Capuzzo and Farrington, 1988).

Effects

Management Question 3: What are the effects of toxic contaminants on marine organisms and populations?

Information Needs

3a. What are the sublethal effects of toxic materials on marine organisms?

3b. What are the implications of toxic effects for populations of marine organisms?

3c. How do synergism, antagonism, and additivity among chemical species affect toxic responses?

3a. What are the sublethal effects of toxic materials on marine organisms?

Resource managers need to recognize and understand the effects of contaminants on marine resources in order to properly manage the resources. In the past, attempts to determine acceptable levels of toxic materials in the marine environment were based mostly on short-term (acute) lethal toxicity tests (LC50, the concentration of a toxicant that will kill 50% of test organisms within a given time, usually 96 hours). These tests of lethality still provide important comparative information and are useful as first-level screening tests in hierarchical testing protocol. However, those interested in managing living resources need information on the impact of toxicants before the plants and animals of interest are killed in order to interdict on behalf of the environment. This requires a knowledge of sublethal effects because organisms may be impaired long before lethality levels are reached. Sublethal responses to toxic pollution may occur at all levels of biological organization, as indicated in Table 4 (Capuzzo and Kester, 1987), and it is important to understand the early warning signs of stress at each level of organization before compensating or adaptive mechanisms fail (Capuzzo, 1981).

Table 4. Sublethal Responses to Toxic Pollution at Various Biological Levels of Organization (Capuzzo and Kester, 1987)

Subcellular	Cellular/Tissue	Organismic	Population	Community
Cytochemical and Biochemical Responses	Cellular and Tissue Responses	Physiological and Behavioral Responses	Changes in Population Structure and Function	Changes in Community Structure and Function
Lysosomal latency	Gametogenic cycle	Respiration	Biomass	Biomass
Enzyme activity	Nutrient storage	Feeding	Productivity	Species abundance
Maximum metabolic flux	Deformity	Excretion	Age and size structure	Species distribution
Energy charge	Neoplasms and tumors	Growth	Mortality	Species diversity
Amino acid labels		Fecundity		Trophic interactions
Blood chemistry		Reproductive effort		Energy flow
Chromosomal abnormalities		Larval viability		Spatial variability
Metallothioneins		Swimming		Temporal variability
Mixed function oxygenases				

Various tests designed to measure sublethal effects at the different biological levels of organization are summarized by Phelps et al. (1987) and include tests to measure the adenylate energy charge (AEC) in mussels as an indication of the amount of energy available from the adenylate pool; sister chromatid exchange (SCE) in polychaete worms as a measure of the interchange of DNA replication products between the arms of a chromosome; gill respirometry to evaluate the rate of change in the condition of fish and bivalves; "scope-for-growth," a physiological index of the amount of energy an organism has available for growth; and various tests for survival, growth, and fecundity.

Future biomonitoring for responses to toxic materials at the population and community levels will require some new techniques which allow measurements of effects in several phylogenetic groups. These new techniques should include tools to allow for unambiguous identification of effects that cannot be the result of fluctuations in environmental variables. Among these responses are proposed studies of the induction and fundamental biochemistry of metal-binding proteins, including metallothioneins (Jenkins and Sanders, 1986), the use of invertebrate bioindicator species to study these proteins, indicators and activation potential of P-450 enzyme complexes, as well as adaptation and validations of short-term genotoxicity tests in fish (Means, 1988).

Sublethal effects of toxicants on bottom-dwelling organisms are of special interest because sediments often act as reservoirs for many toxicants. Recent work at EPA research laboratories in Newport, Oregon, and Narragansett, Rhode Island, has resulted in the development of a sediment bioassay using the benthic amphipods, Rhexopynius and Ampelisca. These tests are 10 days in duration and are more realistic since the animals are placed in containers with sediment -- either natural sediment or sediment from contaminated areas. The animals burrow into the sediment as they do in the natural situation with all the normal interactions between sediment/water/interstitial water operational. The critical value is the LC50, but it is also possible to observe sublethal behavioral effects such as the absence of burrowing activity. Tests such as the sediment toxicity tests are valuable since the duration of the test is longer (10 days vs. the typical 96 hours) and the exposure scenario is more natural. The development of even longer term tests with sublethal effects such as the EC50 (effective concentration) is needed. The EC50 is the concentration of a toxicant required to reduce the test criteria (e.g., shell growth, photosynthesis, body length) by 50%.

Specific opportunities for productive research include development and validation of sublethal toxicity testing procedures with more chemicals and test organisms. Additional information on the concentrations of toxicants that managers must become concerned about and monitoring tools to recognize these conditions would also be useful.

3b. What are the implications of toxic effects for populations of marine organisms?

The range of responses of individual organisms to toxic materials seen in laboratory experiments or field populations is extensive. While further documentation and understanding of sublethal effects would be useful, the most important information gap which relates to all assessment problems is the relationship between effects of toxic materials on individuals (in the laboratory or natural populations) and the integrity of populations. This is because it is often difficult to extrapolate from impacts on a few test animals to the viability of an entire population in the field.

The determination of lethal concentrations in laboratory tests can be accomplished with good precision. A wide variety of tests exist and many have been standardized for management purposes. It is not unreasonable to assume that organisms exposed to equivalent concentrations in the natural environment (to those that produced lethality in the laboratory) will not survive, providing the overall exposure and other conditions are similar. Situations like this may occur in the case of a spill of a toxic chemical.

Populations chronically exposed to toxicants may evolve increased tolerance to the toxicants. This can be a subtle way of detecting contaminants that are stressing the organisms (Luoma, 1977). The increased tolerance may be present only at certain life history stages, and may be accompanied by reduced fitness of the organisms in other ways. For example, mummichogs (Fundulus heteroclitus) from the highly contaminated Newark Bay estuary have developed increased tolerance to methylmercury, but only during embryonic stages (Weis, et al., 1981a; 1987). This adaptation of the embryo is accompanied by reduced salinity tolerance of eggs, decreased growth, earlier sexual maturity, and decreased longevity of adults as compared to reference populations (Toppin et al., 1987). Thus, an intensive study of the biology of a population may be needed to learn the subtle and long-term impacts of toxicants.

Effects such as tumors and other histopathological disorders have been found in demersal fish from a variety of estuaries including Boston Harbor, Massachusetts, the Hudson River Estuary, New York, Southern California, and Puget Sound, Washington. In all cases, there is a variety of pollutants in the system and identification of the cause(s) of the sublethal effects seen is difficult. Some of these same abnormalities have been reproduced in the laboratory with exposure to specific chemicals (e.g., PAHs) found in the contaminated areas. For example, Collier et al. (1986) showed a potential for reproductive toxicity in benthic fish after exposure to organic extracts of contaminated sediment. The contaminated marine sediment contained aromatic and chlorinated hydrocarbons.

Particularly sensitive responses that may show a relationship with population effects include biochemical responses that relate either to energy metabolism and membrane function or to detoxication (such as induction of mixed-function oxygenase activity), and physiological responses such as scope-for-growth or hormonal changes that influence the energy available for growth and reproduction or other aspects of reproductive and developmental processes. These indexes can be integrated by the functional relationship of metabolic function and energy turnover for growth and reproduction. No single index can provide the predictive capability to evaluate population changes, and future studies should be directed at defining the relationship of multiple responses (Capuzzo and Kester, 1987).

Recruitment problems that affect the stability of adult populations are complex and far from resolved. Some species produce eggs and larvae in very large numbers, which are dispersed widely (e.g., bivalves such as mussels). In some cases, recruitment to areas where adults are living may actually come from populations in other areas; in these cases it is difficult to determine the effects of a loss of a percentage of the adults (or even a reduction in the reproductive potential) on the survival of the population as a whole. A better approach might be to monitor certain key species whose reproductive scope is more limited. Many crustacean species such as amphipods produce a limited number of young which are kept in brood pouches. The dispersal process is also limited in many cases since the brooded larvae settle fairly quickly after release. A sublethal response of some of these species is the premature release of young when exposed to toxics chemicals. Some benthic amphipod species are very important in the food chain; they are major components of the diet of demersal fish such as cod and haddock.

One possible approach to this information need is the use of mesocosm experiments such as those conducted at facilities at Narragansett, Rhode Island. Very large flow-through tanks contain communities similar to those in the adjacent water of Narragansett Bay. These facilities have been used to test the effects of a variety of toxicants such as petroleum hydrocarbons and PCBs on communities (Gearing et al., 1979; Wade and Quinn, 1980). One experiment showed that the addition of number 2 fuel oil over many months resulted in uptake by species and major changes in the composition of the benthos. It should be possible to combine results of contaminant exposure to individuals in the laboratory with observed effects in mesocosm experiments and produce estimates of the types of sublethal effects (and levels of exposure) that will affect the stability of populations in model communities.

To determine the implications of toxic effects on populations of marine organisms, research should be conducted to relate contaminant content in sediments, interstitial waters, and biota to changes in benthic biomass, benthic community structure, and recruitment of benthic populations (Capuzzo and Kester, 1987). Demersal fish and shellfish populations with limited or no migratory behavior should be used as models. Concentrations of contaminants in the sediments and interstitial waters should be investigated in relationship to contaminant content of tissues, activity of detoxification enzymes, seasonal alterations in energy reserves, recruitment of juvenile stages, reproductive condition, and the incidence of disease and histopathological conditions (Capuzzo and Kester, 1987).

3c. How do synergism, antagonism, and additivity among chemical species affect toxic responses?

Because of the proximity to urban and industrial centers, contaminated estuaries almost always contain a variety of toxic contaminants, and interactions among these compounds may occur. Synergism occurs when the toxicity of two or more compounds in combination is greater than the sum of their individual toxicities. Antagonism occurs when the presence of two or more compounds together reduces their overall toxicity. Additivity occurs when a mixture of chemicals is approximately equivalent to that expected from a summation of known toxicities of individual chemicals (an algebraic summation of effects) (Rand and Petrocelli, 1984). There has been little research on these types of interactions for many of the compounds of concern, but there are a few cases where each process has been demonstrated.

The presence of other organic contaminants has been found to affect bioaccumulation of individual PAHs. Fortner and Sick (1985), in an investigation of accumulation of naphthalene, a PCB mixture, and benzo(a)pyrene by oysters found several instances where multiple components had antagonistic effects on accumulation. Stein et al. (1984) exposed English sole to sediments labelled with 3H-benzo(a)pyrene and 1C-Aroclor 1254, both singly and together, and found that accumulation of benzo(a)pyrene was enhanced when the fish were exposed to both compounds. Parrish et al. (In press) found various ingredients in drilling fluids, including lead and a biocide, to be additive in their toxicity to mysids.

Methylmercury and cadmium both retard limb regeneration and ecdysis in fiddler crabs, and when crabs in 30 ppt salinity seawater are exposed to a mixture of both metals, an additive interaction occurs in that the toxic effect of both is greater than each singly. When the crabs are subjected to reduced salinity (15 ppt), the effects of cadmium toxicity (singly) are enhanced. However, when methylmercury is added to the cadmium solution at 15 ppt salinity, the effects of the cadmium are somewhat reduced, indicating an antagonistic interaction of the two metals (Weis, 1978). Thus, environmental factors such as salinity, temperature, and pH must be considered with synergism, additivity, and antagonism of chemicals of concern. Indeed, when congenital abnormalities produced in embryos of Fundulus heteroclitus by methylmercury were investigated in relation to possible interactions with salinity, temperature, cadmium, and zinc, it was found that certain anomalies were reduced when cadmium and zinc were present, but reductions in salinity and temperature increased the teratogenecity of the methylmercury (Weis et al., 1981b).

The Coastal and Estuarine Assessment Program and the National Fishery Ecology Program (NOAA) have supported studies in estuarine areas that are contaminated with a variety of pollutants. Included are New Bedford Harbor, Massachusetts; Long Island Sound; San Francisco Bay; and Puget Sound. Studies have involved the effects of toxic compounds on incidence of neoplasia in clams, oysters, and muscles; reproductive success in flounder; reproduction, growth, and survival in lobsters; and the relationship between sediment-associated chemicals and liver neoplasms in English sole and winter flounder. Some of the recent data on synergism and antagonism came from these studies.

In general, past studies have focused on a few compounds presumed to be the major cause of toxicity or sublethal effects seen in their respective environments. These programs should continue to identify the relative contribution of the major contaminants to ecological stress. Toxicity reduction evaluation methods can be used to determine the physical/chemical nature of causative toxicants. By repeating a battery of tests, it is possible to isolate the problem chemicals. Confirmation tests can then be conducted with individual and combinations of toxic substances to identify any synergistic, antagonistic, or additive effects. Resulting data from these laboratory studies can then be related to conditions in the area under study, and the information used to direct management practices for toxic material inputs. Some effluents are so complex that the best approach is to study the toxicity of the whole effluent rather than to attempt to learn the role of each of perhaps hundreds of different chemicals and their interactions in the mixture.

It is important to identify interactive effects (i.e., synergism, additivity, and antagonism) to be able to eventually predict these responses for important classes of marine pollutants. But interactive effect is a complex question, considering the vast numbers of pollutants and environmental factors to be considered. Much research needs to be accomplished before combined toxicities can be predicted based on empirical information.

Conclusions and Recommendations

Discharges and nonpoint source inputs of toxic materials in the coastal environment have contributed to the deterioration of some of these areas, and exposure to these materials has resulted in adverse effects on living marine resources. Although point source discharges of many toxic materials are coming under increased regulatory control, nonpoint sources and atmospheric inputs remain as serious problems. The Federal Government has supported a great deal of research and monitoring concerning the sources, fates, and effects of toxic materials in the marine environment; however, many unanswered questions remain which will require continued Federal support to address. The following conclusions relating to the current state of knowledge concerning sources, fates, and effects of toxic materials in the marine environment have been reached based on the discussion of management questions and the more detailed information needs presented in the previous section.

- In most coastal regions of the country, we do not know the relative contribution of atmospheric inputs and episodic events to chemical contaminant loadings in these areas.

- There is a lack of understanding concerning the processes that control the routes, rates, and reservoirs of various contaminants released into the marine environment.

- For many toxic substances, very little is known concerning their physical chemistry and its effect on bioaccumulation.

- Current understanding of sublethal effects of toxic chemicals is limited, especially with regard to the relationship between effects on individuals and the integrity of populations of living marine resources.

- There is a general lack of understanding of the interactive effects (synergism, addivity, and antagonism) for many important classes of marine pollutants.

Based on these conclusions, the following recommendations are made to improve our understanding of the sources, fates, and effects of toxic materials in the marine environment.

Sources and Loading Rates

The following information is needed to determine the relative significance of atmospheric inputs and episodic events to the chemical contamination of marine environments.

Atmospheric Inputs. Federal efforts directly related to determining the level of atmospheric inputs of toxic contaminants in the aquatic environment have focused primarily on the Great Lakes region. These efforts should continue, and similar monitoring activities should be conducted in several major estuarine areas of the country where atmospheric inputs are suspected to be significant.

Episodic Events. Efforts to evaluate both the loading rates of toxic chemicals due to storm events and the importance of timing of these events with respect to effects on biological activity would provide useful information in this area. This effort would involve more frequent monitoring of selected streams in the drainage system of major estuaries. In addition, more information concerning seasonal patterns of particulate and dissolved trace metals and the chemical speciation of dissolved metals as a function of various hydrographic factors, such as salinity, organic matter, and suspended-sediment concentration would improve our understanding.

Transport and Bioavailability

The following information needs have been identified in order to determine the factors that influence the transport and physical fate of toxic materials in the marine environment and to determine how physico-chemical forms and metabolic processes affect the bioavailability, uptake, and toxicity of toxic contaminants.

Transport and Physical Fate. Research to determine the mechanisms of resuspension and deposition of sediments and associated chemical contaminants and the kinetics of sorption/desorption would be useful. Such research would be related to trace metal partitioning between dissolved and particulate forms, chemical speciation in seawater, and the kinetics of regeneration in bottom waters or release from sediments.

Physico-chemical forms. Our understanding of the physical chemistry of toxic material with respect to bioaccumulation would benefit from further studies. Programs to evaluate toxic materials in the marine environment would include basic physical chemistry research on interactions with seawater and particulate organics. There is a need to develop and strengthen existing sampling and measurement techniques for toxic materials in selected microenvironments. Partition coefficients have been determined for relatively few toxic contaminants. The use of partition coefficients to build models of the fate of toxic material should be expanded.

Metabolic processes. Additional studies to obtain more information on the identity, distribution, and rates of formation of biotransformation products and how mutagen and carcinogen products are transformed (activated/inactivated) and accumulated by marine organisms would be of value. Multicompartment models should be developed to include more organic contaminants and commercially important species. Studies to support model development should include long-term evaluations of uptake and release of problem toxics and the fate of toxics in critical tissues. Monitoring studies should also be developed to include analysis of biotransformation products.

Effects

The following information is needed to help understand the effects of toxic materials on marine organisms and populations.

Sublethal Effects. For a better understanding of sublethal effects, research should address the development and validation of sublethal toxicity tests with more chemicals and test organisms. Monitoring tools to assist in recognizing the presence and levels of toxicants and possible sublethal effects in the field would also benefit from further studies.

Population Effects. Future research studies to evaluate population changes should focus on defining the relationship of multiple responses to toxic contamination. For example, studies should be conducted to determine the relationship between contaminant concentrations in the sediment and interstitial waters and contaminant content of tissues, activity of detoxification enzymes, seasonal alterations in energy reserves, recruitment of juvenile stages, reproductive condition, and incidence of disease and histopathological conditions (Capuzzo and Kester, 1987).

Interactive Effects. Much research would need to be conducted before the combined toxicities of toxic materials could be predicted. The toxicities and sublethal effects of more problem contaminants should be determined to identify their contribution to environmental stress and their mechanisms of impact. Tests should be conducted with individual and combinations of toxic substances to identify synergistic, antagonistic, or additive effects. Research should include a determination of the influence of environmental factors, such as salinity and pH, on synergistic, antagonistic, and additive effects.

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GOAL 2: UNDERSTAND THE SOURCES, FATES, AND EFFECTS OF NUTRIENTS ENTERING THE MARINE ENVIRONMENT AS A RESULT OF HUMAN ACTIVITIES

Excessive anthropogenic nutrient loading to coastal waters is a national concern. A few important areas where nutrient pollution has been identified as a serious problem are the coastal waters off Los Angeles and Louisiana, Boston Harbor, New York Harbor, Buzzards Bay, Long Island Sound, Kaneohe Bay (Hawaii), the Chesapeake Bay, Lake Washington, and the Great Lakes. Degradation of water quality and adverse effects on aquatic and marine biota resulting from anthropogenic nutrient inputs have been well documented. Therefore, understanding the sources, fates, and effects of nutrients entering the marine environment as a result of human activities is one of the six goals of the National Marine Pollution Program.

Goal Definition

Nitrogen and phosphorus are the primary anthropogenic nutrient inputs of concern in coastal waters. Nitrogen is considered the most important nutrient limiting primary productivity in marine and coastal waters, while phosphorus generally limits primary productivity in freshwater. Both nitrogen and phosphorus are important in estuarine waters, depending on the season, total nutrient loadings, and various physical and chemical conditions existing in the estuary. While other nutrients such as silica, carbon, and some trace elements may also be important in specific systems and at certain times (Likens, 1972), the following discussion only addresses nitrogen and phosphorus.

There are two fundamental differences between nutrients and other sources of pollution. Unlike toxic and carcinogenic compounds, nutrients represent basic chemical requirements for primary producers, i.e., photosynthetic plants and microorganisms, and cause their primary harmful effects by stimulating growth to unnatural kinds and amounts. All organisms ultimately depend upon primary producers for food. Thus, alterations in the natural availability and proportions of nutrients have implications not only for green plants and photosynthetic microorganisms, but for entire ecosystems.

Excessive nutrient loading can cause accelerated eutrophication, a condition that is characterized by excessive primary production as a result of extremely rapid growth and large standing crops of phytoplankton. In eutrophic water bodies, the large planktonic biomass decreases the distance that light can penetrate through the water column. Reduced light penetration has been shown to inhibit photosynthesis in deeper waters of some eutrophic estuaries (Pennock, 1986; Pennock and Sharp, 1987), and to affect photosynthetic microorganisms as well as submerged aquatic vegetation (SAV), which grows attached to the bottom. Declines in SAVs result in the loss of valuable habitats for finfish and shellfish as well as decreased oxygen production (Heck and Orth, 1980; Boynton and Heck, 1982; Orth and Moore, 1983; Chesapeake Bay Living Resources Task Force, 1987; Christmas and Jordan, 1987).

In addition to increased turbidity, a large phytoplankton biomass ultimately can lead to oxygen depletion of the water column and sediment as a result of the decomposition of organic matter by microorganisms. Degradation of organic matter is a process that consumes oxygen. Most of this degradation occurs at the sediment surface, but water column effects also can be significant (Kemp et al., 1987; Paerl and Carlton, 1988). Oxygen demand associated with breaking down the enormous quantity of organic matter present in eutrophic water bodies can be greater than the concentration of oxygen within the water or the rate of reaeration. This is especially true for stratified water columns such as those found in many estuaries and lakes. Stratified bottom waters have a restricted ability to replenish oxygen because there is little benthic photosynthesis (due to light attenuation) and mixing with the oxygenated surface waters is restricted. Oxygen concentrations in bottom waters under stratified and eutrophic conditions may decline to extremely low values, e.g., less than 3 mg/l (hypoxia), or in the extreme case, to zero (anoxia).

Eutrophication, hypoxia, and anoxia are not rare phenomena. Today, hypoxia is a characteristic feature in 126 of 131 U.S. estuaries and coastal waters for which adequate data exist (Whitledge, 1985). In the Great Lakes, of 42 identified locations of concern, 21 locations show oxygen depletion associated with eutrophication (GLWQB, 1987). While the greatest number of near coastal and estuarine examples of damage to ecological integrity occur in the temperate zone, there are several severely eutrophic tropical embayments. Nutrient-stressed bays or estuaries occur, for example, in Hawaii, Guam, Puerto Rico, and the Virgin Islands.

There is a vast and growing body of literature addressing sources and effects of nutrients in coastal waters. This chapter is not intended to provide a thorough review of all existing literature on this subject. Here, we attempt to address only those nutrient pollution problem areas that are most important in the context of environmental management. The following discussion of nutrient pollution is divided into three subsections: nutrient source and loading databases; nutrient cycling; and effects of nutrient loading.

Nutrient Sources

Human activities contribute greatly to the quantity of nutrients entering the marine environment. Publicly owned treatment works (POTWs) and industrial dischargers are the main point sources of nutrient loadings. Urban and agricultural runoff and emissions from automobiles and industry are the major nonpoint sources of nutrient inputs to lakes, rivers, and estuaries via surface runoff, groundwater infiltration, and atmospheric deposition. Determination of nutrient loadings requires knowledge of the quantities and timing of nutrient inputs from both point and nonpoint source discharges. As traditional point source inputs of nutrients are controlled, increased attention is being focused on mechanisms of loadings and on monitoring and controlling nonpoint sources of nutrient loadings.

Source Databases

To protect our coastal waters from excess nutrient inputs, quantitative target nutrient loadings are being established on which discharge regulations and limitations can be based. Accurate and timely data on all significant sources of nutrients entering marine environments are needed to set basin-specific targets for loadings. This entails the separation of natural from societal inputs and the establishment of reliable national and regional databases on source types, mechanisms, quantities, and timing of nutrients entering coastal waters.

Source databases initially were used to determine relative contributions of individual sources to overall nutrient loadings and to identify which sources offered the greatest potential for reductions. These databases also may be used to account for total loadings and identify areas of concern, provide input data and refine mathematical models that aid in determining acceptable nutrient loadings, identify both short- and long-term trends in nutrient loadings, evaluate progress toward management goals, and provide direction for management decisions.

An example of an operative source database is the International Joint Commission (IJC) Great Lakes Water Quality Board's (GLWQB) procedures for reporting phosphorus data as required by the Great Lakes Water Quality Agreement of 1978 between the United States and Canada. Monthly effluent data are reported for every point source discharge in the Great Lakes basin. Tributary loadings are quantified using flow data and estimates provided by the U.S. Geological Survey (USGS) and Water Survey, Environment Canada, and river-mouth sampling generally provided by individual states and the province of Ontario. Atmospheric loading estimates are based on data obtained from stations distributed throughout the lakes and are reported as mass flux per unit area. The EPA database (STORET) and the IJC computer are used for the compilation, analysis, and reporting of both United States and Canadian data. From combined data, load estimates are made, summarized, reported, and compared with target loadings (GLWQB, 1987; Dolan, 1988).

Nonpoint Sources

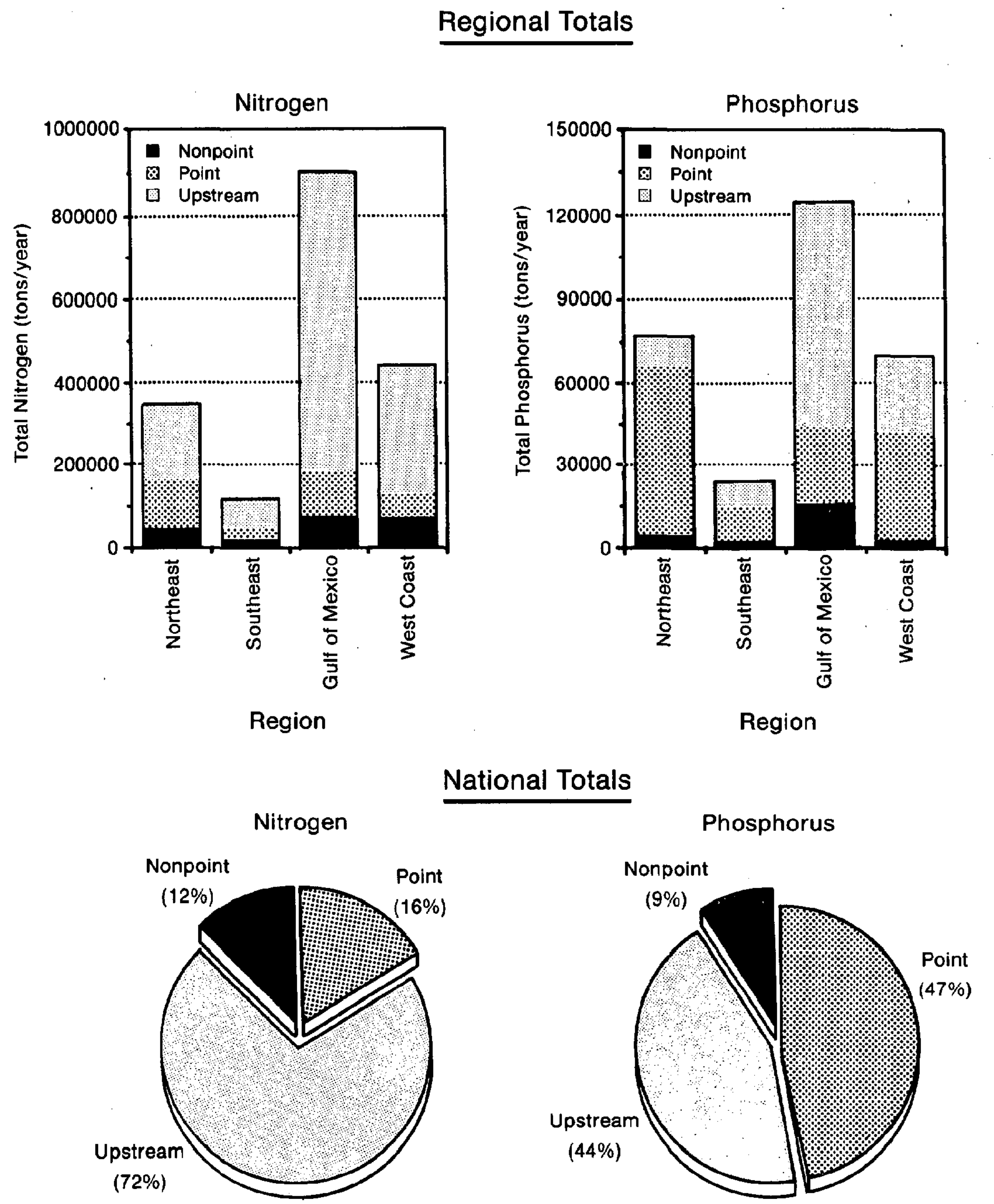
Data representing estimates of nonpoint source nutrient inputs to some lakes and stream channels are available. They have been derived from a number of indirect measurements such as 1) estimates of nutrient inputs from fertilizer applications to farmland; 2) estimates of sediment loss due to erosion calculated using the universal soil-loss equation (or modifications thereof), which incorporates the variables of rainfall, soil erodability, slope gradient and length, vegetative cover, and erosion control practices employed; and 3) by using nonpoint source pollution watershed models. These estimates of nonpoint source nutrient inputs to inland water bodies are supported by data that are collected by the USGS National Stream Water Quality Accounting Network (NASQAN), the joint EPA and U.S. Fish and Wildlife Service (FWS) National Fisheries Survey, and stream monitoring data from a variety of state and municipal sources. The Strategic Assessment Branch (SAB) of NOAA is completing a comprehensive estimate of point and nonpoint source inputs to United States' coastal waters, the National Coastal Discharge Inventory (Basta et al., 1985). These data are based on monitored data and watershed models and include 92 estuaries identified in the SAB's National Estuarine Inventory (in preparation). Figure 9 shows estimated regional and national loadings of nitrogen and phosphorus from point, nonpoint, and upstream sources. As shown in the figure, both point and nonpoint source nutrients contribute significantly to the total loadings, both on national and regional scales.

Establishing accurate databases on nonpoint sources has proved to be a very difficult task, particularly for the atmospheric, groundwater, and "unmonitored area" categories. Estimates indicate that nonpoint source inputs contribute significantly to the total nutrient load of a great number of water bodies. For example, 1985 loading estimates for Lake Erie indicate that over 83% of total phosphorus entering the lake resulted from nonpoint sources (GLWQB, 1987). Nonpoint sources of nitrogen in the Chesapeake Bay range from 62% in dry years to 81% in wet years (EPA, 1983). Relative contributions of nonpoint sources of phosphorus in the Chesapeake Bay range from 31% of total phosphorus loadings in dry years to 69% in wet years.

Atmospheric Deposition

Atmospheric deposition may be a significant nonpoint source of phosphorus to marine and coastal waters. Preliminary data from the Great Lakes indicate that approximately 10% of the total phosphorus loadings to Lake Erie and 30% of the total phosphorus loadings to Lake Superior may be due to atmospheric deposition (GLWQB, 1987). In addition, atmospheric deposition of phosphorus may represent as much as 10% of the total phosphorus contribution of rivers to the oceans (Graham and Duce, 1979; 1981; 1982; Graham et al., 1979). Phosphorus in the atmosphere originates from soil particles as a result of erosion by wind, from organic matter as a result of biological activity (e.g., spores, fungi, and pollen), from sea spray, and from industrial and agricultural emissions.

There are also data that indicate a need for concern over atmospheric deposition of nitrogen. An Environmental Defense Fund Report estimates that 25% or more of the nitrogen reaching coastal waters is from atmospheric deposition (Fisher et al., 1988). Since nitrogen is commonly considered to be the nutrient that limits phytoplankton growth in coastal waters (Ryther and Dunstan, 1971; Parsons et al., 1977; Mann, 1982), contributions from atmospheric sources must be considered when addressing impacts of nonpoint source loadings. Industrial and automobile emissions of sulfates and nitrates combine with atmospheric moisture to form



*Note: upstream sources include all river-borne nutrients entering rivers from sources upstream of coastal counties, whether point or nonpoint.

Figure 9. Total Nitrogen and Phosphorus Loading to Estuaries (NOAA, In preparation).

dilute sulfuric and nitric acid which then may be deposited as acid rain. In one study, acid rain in North Carolina was shown to contain more than twice the concentration of nitrogen as nitrite and nitrate found in nonacid rain. Furthermore, acid rain has been shown to stimulate marine phytoplankton growth in the laboratory 30-70% more than phytoplankton grown in nonacid rain controls (Paerl, 1985). Atmospheric deposition of nitrogen is greatest along the Mid-Atlantic coast where prevailing winds and industrial and automobile emissions interact. Figure 10 illustrates the annual atmospheric deposition of ammonium and nitrate in the continental United States during 1985.

Groundwater and Unmonitored Areas

There is very little information on the role of groundwater as a nutrient source and in nutrient processing in the marine environment (EPA, 1984a; Swain, 1988). Research is currently being conducted on the human health and environmental implications of nitrate in groundwater. Some scientists and managers are concerned that some of the nutrients in groundwater eventually are leached into tributaries and rivers and then are delivered to coastal waters. However, the processes involved in groundwater nutrient delivery are not well understood and quantification of this source cannot currently be done on a basin-wide scale.

Riverine data are essential for calculating nutrient loadings of coastal waters. In the Great Lakes and other areas, loadings from tributaries generally are estimated from daily flow data and river-mouth sampling. However, many areas are unmonitored due to remoteness and sparse populations, while other areas receive only intermittent monitoring for various reasons (GLWQB, 1987; Dolan, 1988). As obvious sources of nutrient loadings are reduced, loadings from groundwater, unmonitored areas, and other nonpoint sources will become more important in management strategy. Although there is a need for better geographic coverage to document total nutrient loadings, it often is impractical or too expensive to monitor all sources. Therefore, estimates commonly are made by extrapolating data from comparable monitored areas.

Nutrient Models

Models that attempt to simulate complex interactions of nutrient loadings and ecosystem responses incorporate appropriate mechanisms and scales depicting natural processes and can be useful tools to aid in our understanding of aquatic ecosystems. Model-based predictions should be used cautiously and be verified by research and monitoring efforts in developing management decisions. The comparison of model-based predictions with data from natural systems is often helpful in illuminating important relationships that have not been addressed or are incompletely understood (Pilson, 1984). Conceptual and mathematical nutrient loading and effects models are used to identify areas where additional research is needed and to help understand and eventually to predict how nutrient loadings affect coastal ecosystems.

By contributing to the understanding and prediction of the consequences of nutrient loadings and mitigation efforts, models are useful management tools. Nutrient budgets can be estimated from basin-specific models that estimate the quantities and timing of all point and nonpoint source nutrient loadings into receiving waters. Mathematical models of water and ecosystem quality may use such estimates to predict the fate and effects of nutrient loadings to an ecosystem. A combination of these models can be employed to develop target nutrient loadings relative to the assimilative capacity of a basin.

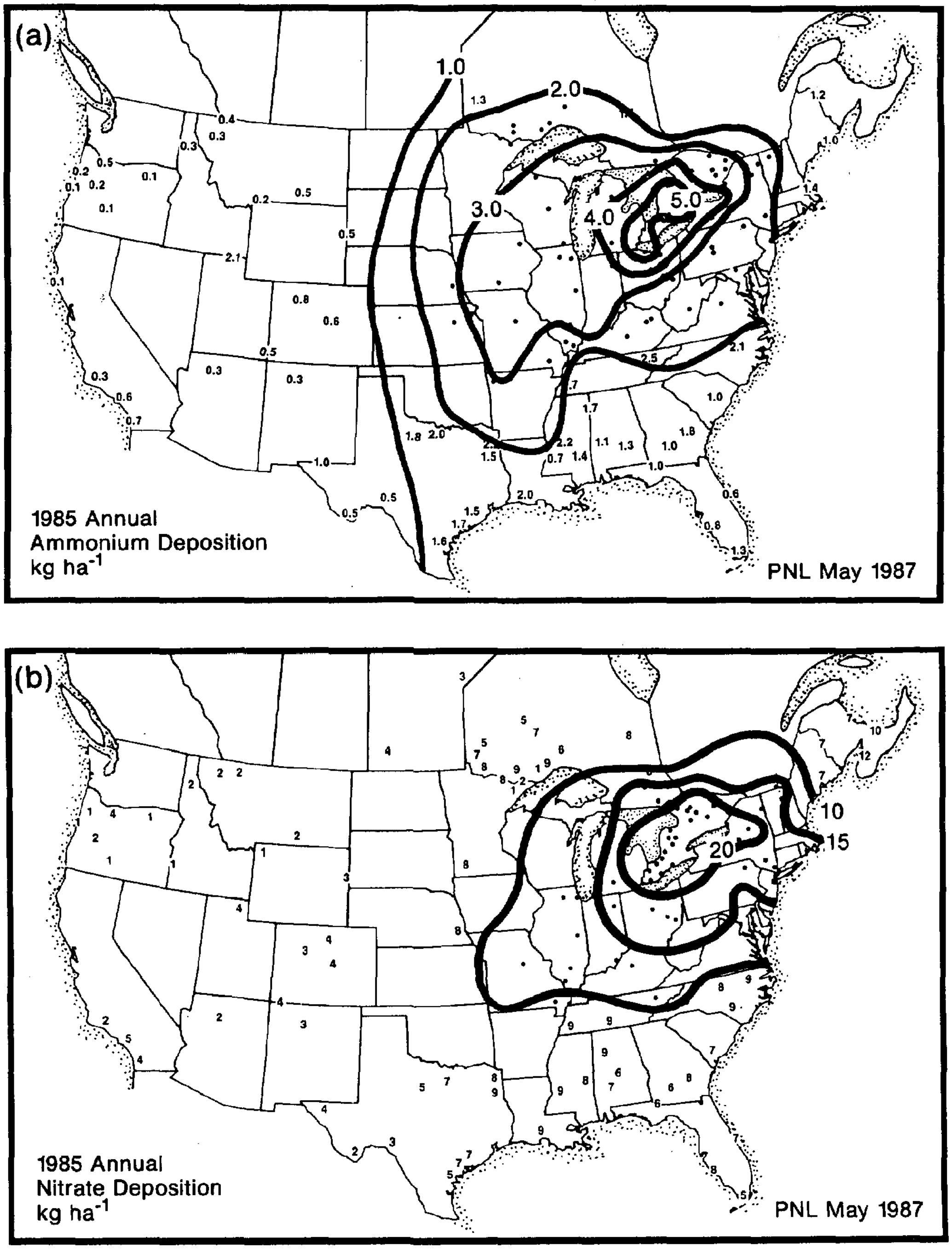


Figure 10. 1985 Annual Composite Distribution of (a) NH_4+ and (b) NO_3− Atmospheric Deposition (NAPAP, 1987)

The complexity of aquatic systems often necessitates that nutrient loading and effects models attain high levels of sophistication. Data requirements for these models are sometimes severe and costly. Models should be developed that require the minimum amount of data necessary to address the questions for which the model was developed. Development of nutrient loading and effects models requires data on timing, type, mechanisms, and quantities of nutrient inputs to a basin. Data about physical and biological characteristics of a basin are also essential. In coastal areas where nutrient pollution is sometimes a serious problem, systems for regular monitoring, reporting, and synthesis of data are needed, both for nutrient inputs and for ambient biotic and abiotic conditions. Such models have been developed for Saginaw Bay, Lake Huron (Bierman and Dolan, 1981; Bierman et al., 1984), and for the Chesapeake Bay (Fitzpatrick, 1987).

Loading models must assess the contribution of both allochthonous (i.e., sources originating from outside a system) and autochthonous (i.e., sources originating from within a system) nutrient inputs. It is largely accepted that increased allochthonous loadings of nutrients can lead to increased primary production (Malone, 1987). However, the quantitative relationships between changes in allochthonous inputs to a water body and subsequent changes in water quality and ecosystem response parameters are poorly understood and difficult to model (Bierman et al., 1984). These difficulties arise in part from the effect of autochthonous sources that may represent significant inputs to the total nutrient loadings of a water body. In the Chesapeake Bay, for example, recycled nitrogen and phosphorus may account for approximately 90% of the total annual supply of these nutrients (Fisher and Doyle, 1987). Although management has little control over autochthonous loadings and must concentrate on control of anthropogenic sources, an accurate determination of effective target nutrient loadings necessitates understanding the relative contribution and effects of all sources of nutrient inputs.

One method of decreasing or at least bounding uncertainty within reasonable limits is the use of nonmathematical models that borrow from both statistical and logical inference methods. The outcome prediction from these computerized conceptual models is based on sequences of rules being triggered by either a truth test or an action, which leads to an outcome dictated by logic and summed algebraicly. By comparing different conditions in combinations, different outcomes may be contrasted and each outcome will produce a probability score based on a consensus of expert practitioners. These are called "expert systems" (Prager, 1988).

Nutrient Cycling

In a sense, nutrients have no ultimate fate. Nutrients are continuously cycled and recycled within the biosphere. The fate of a nutrient depends on the temporal and spatial scale considered. When discussing nutrient sources, fates, and effects, it is essential to understand that they are interrelated on a global scale. Although a complete discussion of nutrient cycling is not within the scope of this chapter, a basic understanding of nitrogen and phosphorus cycling is a prerequisite to any discussion of nutrient fates and effects.

The Nitrogen Cycle

The most important nitrogen cycle processes are illustrated in Figure 11. Various forms of nitrogen enter aquatic systems from both anthropogenic and natural sources. The most abundant natural source of nitrogen is molecular nitrogen (N_2), which comprises approximately

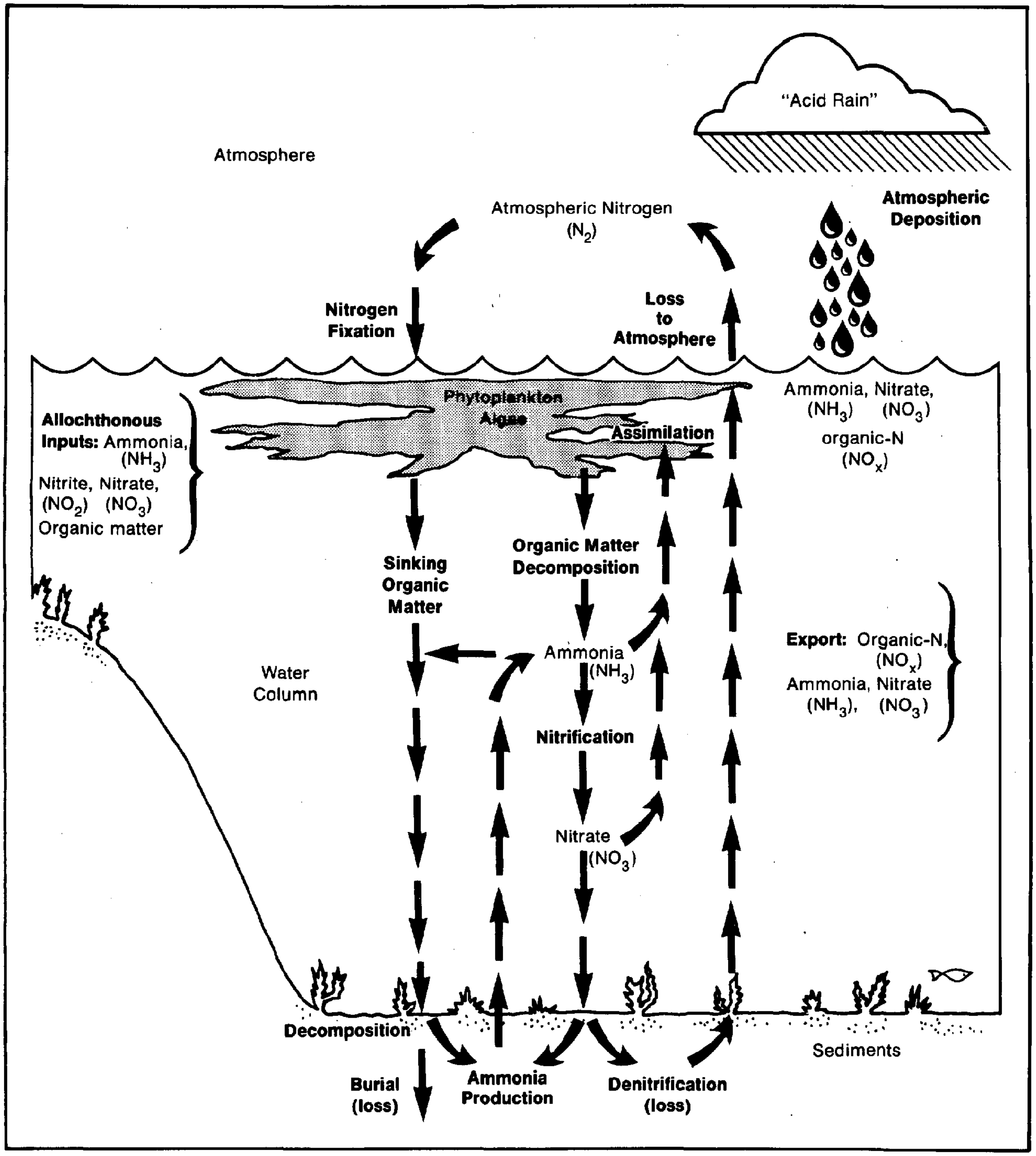


Figure 11. Simplified Diagram of Nitrogen Cycling in an Estuary.

78% of the Earth's atmosphere. Only a small number of microorganisms are able to use this vast pool directly for growth and metabolism. The biological process of converting N_2 into forms that can be used by most organisms is called nitrogen fixation.

Some nitrogen available for biotic growth in the marine environment is ammonia liberated from decomposing organic matter (Painter, 1970). Depending on environmental conditions, this ammonia may be bound to soil or sediment particles, may undergo volatilization (Idelovitch and Michail, 1981), or may be assimilated directly by bacteria or algae (Painter, 1970; Parry, 1985). In aerobic (oxygenated) environments, ammonia can be oxidized to nitrite and nitrate by nitrifying bacteria. This process, nitrification, is also important because it consumes oxygen and can contribute significantly to oxygen demand of water bodies and sediment (Fenchel and Blackburn, 1979). Wezernak and Gannon (1967) found in one study that 3.22 parts oxygen are used for the oxidation of 1 part ammonia and that 1.11 parts oxygen are required for the oxidation of 1 part of nitrite to nitrate.

Nitrate, like ammonia, may be assimilated directly by some phytoplankton. In addition, nitrate can be used by certain microorganisms under anaerobic (oxygen-free) conditions rather than oxygen in different energy-producing metabolic pathways. This process, denitrification, results in reduction of nitrate by stages to molecular nitrogen, which is lost to the atmosphere. This reduces the nitrogen available for use by all but a relatively few nitrogen-fixing organisms. Denitrification has been shown to occur in suspended particles, sediments, anoxic water bodies, and anoxic "microzones" within otherwise aerobic environments (Greenblott, 1987; Paerl and Carlton, 1988). Research indicates that denitrification can account for losses of 30-50% of the nitrogen inputs to coastal waters, and is therefore a major sink or loss in the nitrogen budget.

Complexity of nitrogen cycling makes accurate, quantitative analyses and modeling of nitrogen cycling in continuously flowing environments difficult. Ammonia concentrations are affected by all ammonia reactions: nitrification, ammonia uptake, oxidation of organic nitrogen, equilibrium, and conversion of ammonia to organic nitrogen for cell synthesis. Nitrate concentrations are affected by nitrification, denitrification, respiratory nitrate reduction, and assimilative nitrate reduction. All of these processes are affected by pH, dissolved oxygen, temperature, pollution, and stream flow (Ruane and Krenkel, 1978; Remacle and DeLaval, 1978; Cooper, 1984).

The Phosphorus Cycle

The phosphorus cycle in aquatic systems is less complicated than the nitrogen cycle because inorganic phosphorus is found in relatively few forms. Phosphorus has no major volatile phase and is rarely reduced or oxidized under most natural conditions (Brock, 1979). In most unpolluted water bodies, the only significant pool of biologically available inorganic phosphorus is orthophosphate. Most phosphorus in the water column is organic phosphorus. More than 90% of phosphorus in lake water is found as organic phosphate in cellular constituents of living matter, or it is adsorbed to inorganic and dead particulate organic matter (Wetzel, 1975). Orthophosphate is generally the preferred form of phosphorus among marine phytoplankton. Rapid exchange of phosphorus between seawater and phytoplankton, and zooplankton grazing and excretion allows rapid regeneration of phosphorus within planktonic food webs. Estimates of phosphorus cycling within the water column indicate that allochthonous phosphorus inputs are recycled from 30 to 120 times before being exported to the ocean or buried in sediment (Fisher and Doyle, 1987).

Exchange of phosphorus between sediment and overlying waters is an important component of phosphorus cycling. Sediment-water phosphorus exchange (i.e., phosphorus regeneration to the water column) is related to several physical, chemical, and biological factors associated with mineral-water equilibria, sorption processes, oxygen-dependent chemical interactions, and activities of bacteria, fungi, plankton, and invertebrates. Oxygen content at the sediment-water interface is the most important feature regulating phosphorus exchange. Under anoxic conditions, phosphorus in sediment may move rapidly into overlying water where it can be used by phytoplankton (Wetzel, 1975). In the Chesapeake Bay, the rate of phosphorus regeneration from sediment increases dramatically when oxygen concentrations in overlying water fall below 2 mg/l (Webb and D'Elia, 1980).

Effects of Nutrients

Although increased primary productivity resulting from intentional nutrient inputs has been shown to increase fish stocks in some experimental systems, the possible increase of fisheries in naturally productive systems is generally considered insignificant when compared with deleterious effects of eutrophication (Nixon et al., 1986b). This discussion focuses on these effects as they relate directly to health and preservation of living aquatic resources. Hypoxia or anoxia and consequent major changes in food web dynamics are the two most conspicuous effects of eutrophication in the marine environment.

Hypoxia and Anoxia

Hypoxia and anoxia can affect nutrient cycling, mobilization and production of toxins, trophic structures, and can kill organisms directly. Under normal aerobic conditions, nutrients and toxins in sediment may be trapped by an oxygenated "microzone" at the sediment-water interface. During hypoxic or anoxic conditions this microzone deteriorates, allowing some nutrients, such as phosphate (Webb and D'Elia, 1980), ammonia and nitrate (Cerco, 1985 as reviewed by Garber, 1987), and sediment-bound contaminants such as Cs, Mn, Co, Zn, and Cd (Santschi et al., 1986) to pass freely from the sediment. Hydrogen sulfide (H_2S) is a toxic gas which is produced in both the sediment and the water column by bacteria under anoxic conditions. In addition to its direct toxicity, oxidation of H_2S consumes oxygen and contributes to maintenance of hypoxic or anoxic conditions (Tuttle et al., 1987). Under aerobic conditions, sediment acts as a nitrogen sink. Nitrate produced during nitrification in the water column is reduced to N_2 by bacteria in anoxic sediment. However, nitrification is inhibited during low oxygen conditions and the process of nitrogen removal from the water column in this manner ceases.

Hypoxia or anoxia also can cause stress to organisms through habitat compression (i.e., a decrease in the spatial or temporal extent of available habitat required for normal growth and reproduction) (Uye et al., 1979; Coutant, 1985; Price et al., 1985). Stress related to habitat compression may result in decreased reproductive capability, increased crowding, disease, overharvest, and direct mortality. Habitat compression affects several commercially important species adversely, including striped bass (Morone saxatilis), American shad (Alosa sapidissima), blueback herring (Alosa aestivalis), and adult alewife (Alosa pseudoharengus) (Coutant, 1985; Coutant and Benson, 1987).

Trophic Structure Alterations

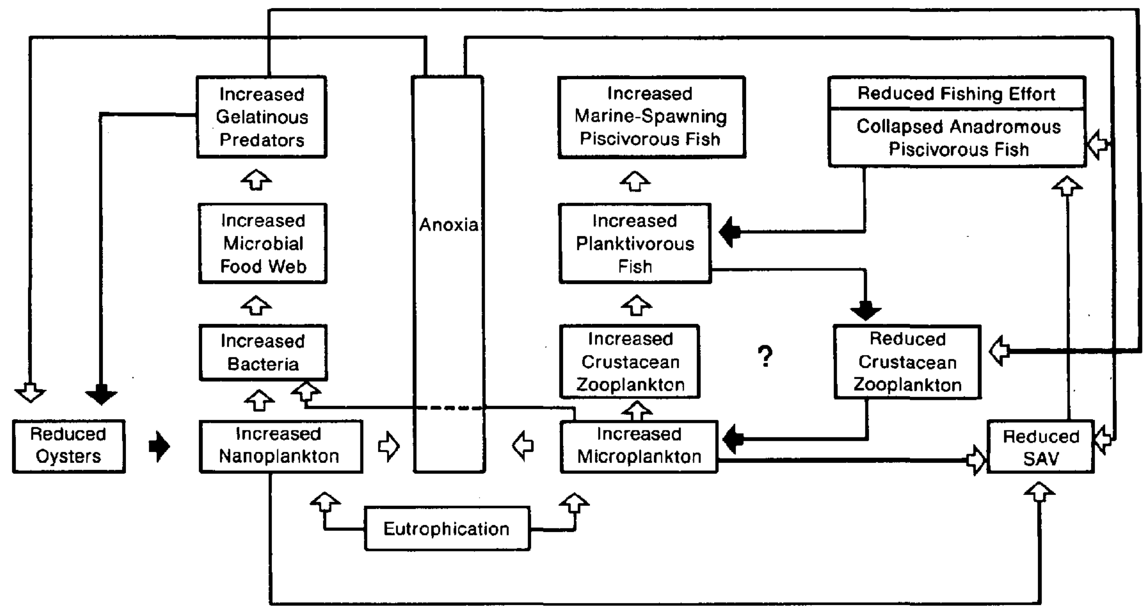
Verity (1987) reviewed how eutrophication may impact an ecosystem by altering species distribution and abundance of both primary producers and consumers. Many factors interact to drive changes in primary producer and consumer populations. These include supply, relative availability, and timing of toxin and nutrient inputs, and various physical characteristics of the estuary such as temperature, turbidity, current, and water column stratification (Grassle and Grassle, 1984; Sullivan and Ritacco, 1985). Phytoplankton community structure also may be altered by differential grazing pressures (Oviatt et al., 1986; Verity, 1987; Paerl, 1988a).

Diatoms are thought to provide the primary energy source for traditional food webs that support teleosts (i.e., finfish) as top predators (Greve and Parsons, 1977; Gearing et al., 1984; Elster and Ohle, 1985). Evidence suggests that eutrophication can cause a shifting in plankton populations from larger, "more desirable" diatom-dominated communities to smaller, "less desirable" flagellate- and cyanobacterial-dominated communities (Smayda, 1983). Acceptability of these smaller species as food by grazers is variable and depends on concentration, digestibility, presence of lethal or inhibitory mechanisms, size, and nutritional value (Silver and Alldredge, 1981; Johnson et al., 1982). By changing food supply available to herbivorous organisms, eutrophication may alter species distribution of higher trophic-level populations (Gearing et al., 1984; Grassle and Grassle, 1984; Grassle et al., 1985; Elster and Ohle, 1985; Nixon et al., 1986b; Fulton and Paerl, 1987).

Alternatively, changes in type and distribution of higher trophic-level herbivores and predators can have a cascading effect all the way down the food web to primary producers. Predation may limit certain species and affect composition even where essential nutrients are not limiting, as in eutrophic waters. For example, increases in abundance of planktivorous fish species (e.g., menhaden) may contribute to dominance by nanoplankton (extremely small species with a diameter of less than 4 um). This may be the result of selective grazing on larger species of phytoplankton (thereby reducing grazing pressure and increasing the competitive advantage of small phytoplankton species), and by the release of nutrients that support growth of small cells (Verity, 1987).

Dominance of phytoplankton communities by inedible or less desirable species may divert energy and organic matter from "higher" trophic levels typically dominated by finfish to microbial-bacterial food webs (Verity, 1987). Bacterial metabolism probably is enhanced indirectly by an overabundance of organic matter available as a result of a large proportion of the primary production not being consumed or assimilated by grazers. In addition, bacteria provide a major component of the diets of heterotrophic (nonprimary producing) nanoplankton. Combined oxygen utilization of heterotrophic bacteria and nanoplankton appear to contribute significantly to total oxygen demand and development of anoxia. Figure 12 summarizes the most important trophic-level interactions described above.

There is no clear and simple answer to the question of how eutrophication affects trophic-level structures. Man's activities increase primary productivity from below through eutrophication. This induces changes from above like predation, disease, and anoxia. The overall effect may be to select for small plankton which support an active microbial food web, shunting nutrients away from "traditional" predators (i.e., away from fish as top carnivores). This constitutes a mechanism for serious adverse impacts on commercial fisheries. Such an ecosystem may favor gelatinous zooplankton (coelenterates and ctenophores) as top carnivores, whose low-growth efficiencies make them a virtual trophic cul-de-sac (Verity, 1987).



Note: Clear arrows define pathways that appear to be strongly influenced by "bottom-up" or source control. Bold arrows show trophic interactions in which "top-down" or sink control appears dominant. Pathways that appear to be less significant are not illustrated for purposes of clarity. Note that most of the changes in stock sizes to the right of the anoxia compartment have been documented, while those to left await confirmation.

Figure 12. Flow Chart Illustrating Some Hypothetical Trophic Linkages That May Be Significant in the Chesapeake Bay (Verity, 1987).

Federal Role

This section discusses the Federal legislation, regulations, and programs that address the issue of sources, fates, and effects of nutrients in the marine environment. Additional discussions of Federal programs as related to specific information needs are presented under the management questions that follow this review of the Federal role. More detailed information on the Federal programs and projects that address the issue of nutrients in the marine environment can be found in the National Marine Pollution Program, Summary of Federal Programs and Projects (NOAA, 1987).

Federal Legislation and Regulations

The Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), also known as the Ocean Dumping Act, and the Federal Water Pollution Control Act (FWPCA, as amended) are the two primary environmental laws governing the input of sewage treatment and industrial wastes to the marine environment. The FWPCA is also the only Federal legislative authority relating to the control of nonpoint sources of pollution (including nutrient inputs).

The Ocean Dumping Act was enacted, in part, "to regulate ocean dumping of all materials and prevent or strictly limit the dumping of any materials that would adversely affect human health, welfare, and amenities, the marine environment, ecological systems, or economic potentialities." A 1977 amendment to the Act mandated the cessation (after December 31, 1981) of ocean dumping of sewage sludge that unreasonably degrades the marine environment. Under Title I of MPRSA, EPA has the authority to designate and manage dump sites, develop criteria to evaluate ocean dumping permit applications, and review, award, and enforce ocean dumping permits. Under EPA's ocean dumping regulation, permits are issued in accordance with the criteria of 40 CFR Part 227, which include specific limitations on the types and quantities of certain materials that may be dumped, an assessment of the need for ocean dumping, the availability of alternatives to ocean dumping, and an assessment of the impact of the proposed dumping on aesthetic, recreational, and economic values as well as other uses of the ocean.

Title II of MPRSA specifically mandates research on the disposal of sewage treatment wastes in the marine environment. The EPA is authorized to conduct research, investigations, experiments, and studies in order to determine means of developing disposal alternatives, and to minimize or end ocean dumping of material that may unreasonably degrade or endanger human health or the marine environment. Also under Title II, the National Oceanic and Atmospheric Administration is responsible for monitoring and research activities regarding the effects of ocean dumping.

The FWPCA and amendments (Clean Water Act of 1981 and Water Quality Act of 1987) govern the disposal of municipal and industrial waste by pipeline discharge into surface waters, including marine waters and the Great Lakes. Section 402 of the Clean Water Act establishes the EPA permit program, which limits pollutants that can be discharged to surface waters of the United States. Under Section 403(c), EPA established regulations that require ocean discharges to meet certain criteria and standards. Discharges that meet the requirements of EPA, or approved State-administered programs, are issued National Pollution Discharge Elimination System (NPDES) permits. Under 301(h), EPA can grant waivers of mandatory secondary treatment to publicly owned treatment plants (POTW's) requirements if certain conditions are met, including an ongoing monitoring program of the receiving environment that includes biota in the vicinity of an outfall and at a suitable reference station not under the outfall's influence.

The 1987 amendments to FWPCA (the Water Quality Act) include provisions for the management of nonpoint sources of pollution. Section 319 of the Act establishes a national policy requiring that controls of nonpoint sources of pollution be developed and implemented ".... in an expeditious manner." The Act requires each State to identify waters that cannot maintain applicable water quality standards without additional action to control nonpoint sources of pollution. It also requires States to identify nonpoint sources that significantly contribute to pollution in such waters and to describe programs for controlling these sources.

Federal Programs

The U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture (USDA) are the major supporters of nutrient research and monitoring in the marine environment. Other agencies conducting nutrient-related activities include the U.S. Fish and Wildlife Service (FWS) and the National Aeronautics and Space Administration (NASA).

Most of EPA's marine nutrient research activities are conducted by the agency's Environmental Research Laboratories, the National Estuary Program, and the Chesapeake Bay Program. Related activities include research on nutrient loadings in estuaries and the assimilative capacity of estuaries for nutrients. In the Chesapeake Bay Program, EPA coordinates pollution research, monitoring, and management of the Bay by identifying sources, fate, and effects of nutrient pollutants. The EPA also supports nutrient studies in the Great Lakes Region. Activities include monitoring of nutrient loadings from the atmosphere and nutrient transport from lake tributaries, and evaluations of the effectiveness of agricultural conservation practices in reducing nutrient loadings.

NOAA's nutrient research and monitoring activities are conducted primarily by the National Marine Fisheries Service (NMFS), the Office of Oceanic and Atmospheric Research (OAR), and the National Ocean Service (NOS). NMFS's related research is focused on the effects of various nutrient input on marine habitats and fisheries. The agency conducts research to determine the extent of environmental degradation caused by various contaminants, including nutrients, in estuarine and coastal ocean environments. Included are studies to assess the extent and severity of eutrophication and to determine the processes governing dissolved oxygen levels in estuaries and coastal waters. NMFS also monitors the sources, fates, and effects of nutrient inputs on living marine resources and the occurrence of hypoxic conditions at ocean dump sites. Most of OAR's nutrient-related research is funded through the Sea Grant Ocean Pollution Program. Related activities supported by the Sea Grant Program include research on the transport and cycling of nutrients in estuarine, oceanic, and Great Lakes ecosystems; the causes of oxygen depletion that lead to anoxic/hypoxic conditions in these ecosystems; and the effects of low-dissolved oxygen on living marine resources and their habitats. Effects studied include research into structural and functional alterations of planktonic food chains in response to blue-green algae blooms and changes in water quality and productivity in nitrogen-enriched coastal ecosystems. The NOS conducts research and monitoring activities to determine the potential causes and extent of oxygen depletion in coastal waters of the United States. The NOS monitors the levels of dissolved oxygen, nutrients, and chlorophyll in the context of eutrophication/hypoxia in coastal waters, and evaluates the contribution to oxygen demand from phytoplankton blooms sinking to bottom waters and sediments. The Strategic Assessments Branch of NOS is developing a comprehensive inventory of pollutant discharges into coastal waters of the United States and is developing a set of computer programs to maintain the data and to conduct analyses.

The USDA conducts research on pollution problems caused by agricultural and forestry practices on downstream and estuarine ecosystems. Studies include research related to the chemical and physical transport and effects of excess nutrients on the estuarine environment. The agency also studies the contamination of groundwater and aquifers from septic system drain fields and monitors soil and crop application of chemicals, sludges, manure, and other wastes.

The FWS conducts research to determine the pathways by which nutrients enter estuaries and to understand high marsh nutrient cycling. The agency also studies the effects of Great Lakes tributary inflow and resuspension of lake sediments on nutrient loading and water quality in nearshore waters and adjacent marshlands. NASA performs research to understand global oceanic primary productivity and phytoplankton distribution. Related studies address the impacts of phytoplankton distribution on living marine resources and global carbon and nitrogen cycles.

Management Questions and Information Needs

Nutrients affect virtually every aspect of the marine environment. Human activities contribute nutrient inputs far in excess of the environment's ability to assimilate them. Adverse impacts on our coastal waters already have occurred. Implications for future reduction of fish and wildlife populations and degradation of water quality must be considered seriously. At risk are the commercial, recreational, and aesthetic values of our coastal waters.

The following is a list of management questions that highlight the most important and least understood aspects of the nutrient problem. Additional data and information on these issues would promote more effective management of nutrient inputs to the marine environment.

Management Question 1: What are the amounts and rates of nutrient addition to the marine environment?

Management Question 2: How do nutrient inputs affect marine ecosystems?

Management Question 3: What causes hypoxia and anoxia in coastal environments?

Management Question 4: Are conventional analytical methodologies adequate for nutrient research?

This section includes a discussion of the rationale, current efforts, and opportunities for additional work associated with the information needs under each management question.

Amounts and Rates of Nutrient Inputs

Management Question 1: What are the amounts and rates of nutrient addition to the marine environment?

Information Needs

1a. How much nitrogen and phosphorus enter from the atmosphere and through groundwater?

1b. How adequate are current models for estimating nutrient inputs?

1c. What is the significance of seasonal and climatic events to annual nutrient budgets?

1a. How much nitrogen and phosphorus enter from the atmosphere and through groundwater?

Management of nutrient inputs requires accurate information on sources and magnitudes of nutrient loadings into the nation's estuaries. Over the past two decades, considerable Federal effort has gone into development of source databases. These databases are used in generating nutrient loading data and for the modelling of acceptable levels of nutrient inputs to coastal waters. Using these databases, reasonable estimates can be made for nutrients delivered from point sources in many estuaries. Data representing nutrient loadings from nonpoint sources are much less available and reliable, particularly atmospheric and groundwater sources. Ten years ago, atmospheric and groundwater nutrient loadings were considered relatively insignificant compared with point source contributions. As point source discharges are coming under increased control and better nutrient budgets are made, atmospheric and groundwater sources are coming under increased scrutiny.

Acid rain contains sulfuric acid (H_2SO_4) and nitric acid (HNO_3). When nitric acid is dissolved in water, it dissociates to yield nitrate (NO_3^-) and the hydrogen ion (H^+). Increases in nitrate concentrations observed in the Great Lakes may result in part from atmospheric deposition in the form of acid rain (GLWQB, 1987). There are also indications that under certain conditions, inputs of nitrogen in the form of nitrate from acid rain may contribute substantially to the total nitrogen of coastal waters. Studies of atmospheric inputs to the near surface waters along the coast of North Carolina demonstrate that impacts of nitrogen loading from atmospheric sources (i.e., acid rain) are detectable and may be important in shaping the patterns and magnitude of phytoplankton production. Normal rainwater (nonacid rain) in North Carolina typically contains 5 to 20 uM NO_3^-/l. During acid rain events much higher concentrations, as high as 300 uM NO_3^-/l, have been observed (Paerl, 1987). Indications are that during acid rain episodes as much as 30 to 40% of the nitrogen loading may be attributed to atmospheric inputs (Paerl, 1988b).

Direct funding for research and monitoring of atmospheric loadings currently is provided by EPA's Great Lakes Program. Development of sampling and monitoring technology and quantification of atmospheric nutrient loadings are being studied for the Great Lakes only. There is a paucity of information on atmospheric nutrient loadings to marine systems.

There is also very little information on the role of groundwater as a nutrient source and in nutrient processing. Groundwater hydrology is a relatively new and imprecise science, and since there is no national database on groundwater contamination, it is difficult to estimate its relative contribution to nutrient loadings (EPA, 1984a). Groundwater models are based on land use and do not account for nutrient processing within soil-aquifer systems. Relevant processes include transformations that can actually reduce nutrient concentrations in groundwater (e.g., denitrification and assimilation) and processes that contribute to nutrient loadings (e.g., nitrogen fixation and mineral dissolution).

To develop a thorough understanding of nutrient sources to the marine environment, basic research addressing atmospheric and groundwater inputs would need to be initiated or expanded where it already exists. This research would focus on developing reliable methodologies for determining atmospheric nutrient contributions and budgets to marine systems and on assessing relative contributions (both wet and dryfall) as compared with other nutrient sources in specific systems and regions.

1b. How adequate are current models for estimating nutrient inputs?

Freshwater and marine systems are extremely complex. Nutrient loading models must attain a high level of sophistication in order to simulate accurately what occurs in these systems. For this reason, systems for obtaining and synthesizing data are needed--both of nutrient inputs and of ambient environmental conditions. Source databases should be developed to identify and quantify conditions of concern and to provide baseline data useful for evaluating management decisions, including assessing the effectiveness of management actions.

Several databases developed by the Federal agencies and departments have relevance to nutrient research, development, and monitoring. Some of these include EPA's STORET, National Eutrophication Study Database and Large Lakes Research Laboratory, and Permit Compliance System (PCS) developed under the auspices of the National Pollutant Discharge Elimination System (NPDES); NOAA's Regional Coastal Information Center Network, and Earth Resource Observation System; USGS's National Water Data System and National Water Data Exchange; USDA's Agriculture Water Data Laboratory; and DOI's Office of Water Research and Technology (EPA, 1984b; NOAA, 1985; Multer and Kemp, 1986). These and other relevant databases should be reviewed to determine their applicability to nutrient research and to identify overlap and information gaps.

Use of nutrient loading models, together with effects models, can aid in understanding complex interactions of nutrient loadings and aquatic ecosystems. In addition, such models can be useful in developing monitoring strategies by providing insight into which parameters are most indicative of changes in the ecosystem. However, mathematical models alone are insufficient to address all the complexities of coastal ecosystems. The enormous number of variables found in natural coastal ecosystems often frustrates researchers attempting to determine causal relationships between nutrient inputs and effects.

Because of this, physical models of ecosystems, i.e., meso- and microcosms, are built. Physical scale models of ecosystems have many advantages for researchers, including the ability to integrate the uncertainty implicit in simulation over a whole process, such as respiration, photosynthesis, or other integrative biological processes of an ecosystem. These systems also have very defined physical boundaries and parameters and an ability to simulate simplified natural systems at relatively low operating costs (Oviatt et al. 1984; Pilson, 1984). An example of an operating mesocosm is the Marine Ecosystems Research Laboratory (MERL), which is located at the University of Rhode Island and supported by EPA and others. The MERL mesocosms have been used in a variety of research projects, including the study of nutrient cycling and effects of eutrophication in Narragansett Bay, Rhode Island (Gearing et al., 1984; Hobbie and Cole, 1984; Oviatt et al., 1984; Berounsky and Nixon, 1985; Kelly et al., 1985; Pilson, 1985; Oviatt et al., 1986; Rudnick and Oviatt, 1986), the effects of nutrients on benthic and zooplankton populations (Grassle and Grassle, 1984; Grassle et al., 1985; Sullivan and Ritacco, 1985), the fates of pollutants including nutrients (Nixon et al., 1986a), and the effects of benthic organisms on nutrient cycling (Doering et al., 1987). This research has been valuable in developing and improving mathematical models, testing hypotheses, and providing insight into processes occurring in natural systems.

Direct funding for the development of models to estimate nutrient loadings into estuaries is supported by EPA under its Division of Groundwater Protection, National Estuary Program (Near Coastal Waters Initiative), and Great Lakes Program (working closely with the U.S.-Canada International Joint Commission). Also, funding for the development of predictive models is provided by the USDA Nonpoint Source Contaminants Program, the USGS Water Resources Division, the National Science Foundation Global Ocean Flux Program, and the NOAA Strategic Assessment Branch. The EPA and COE are developing a very sophisticated 3-dimensional, time-variable eutrophication model for the Chesapeake Bay.

Although advances have been made in the development of predictive models, major improvements in the future depend upon availability of better source data estimates in the following areas: atmospheric and groundwater loadings, inputs from areas that are not being monitored, and the quantities of nutrients delivered to coastal waters during episodic and climatic events such as heavy rains and floods. Databases are of little utility if the data can not be converted into useful management information. Better algorithms, improved computer technology, and a better understanding of nutrient behavior in marine ecosystems would allow these data to be used fully.

1c. What is the significance of seasonal and climatic events to annual nutrient budgets?

Much of the difference between predicted and actual tributary nutrient loadings is due to the design of tributary monitoring programs and timing of samplings. Predictions of nutrient inputs must account for major episodic events that affect stream flow, such as storm events and spring runoff from snow melt. Inadequate sampling of episodic events in Michigan's Saginaw River resulted in unsatisfactory 1985 loading estimates. "The 1985 estimate and its 95% confidence limits are very large (1,532 $\pm$ 1,917 tons), while the target load for all of Saginaw Bay is 440 tons. These very wide confidence limits stem from lack of event sampling" (GLWQB, 1987). This observation also is supported by the extensive monitoring program of the Potomac River conducted by the Metropolitan Washington Council of Governments and the Maryland Department of the Environment (Curtis, 1987). Nutrient loadings at the Potomac River fall line were estimated as the product of flow rate and sample concentrations. The study, conducted between January 1983 and April 1987, consisted of 76 storm composite samples and 115 base flow discrete samples. Results indicated that 70 to 97% of annual nutrient and sediment loads were delivered during storm events. Over 40% of the total phosphorus load and 25% of the total nitrogen load during an 8-year period were delivered during six flood events. Knowledge of relationships between tributary flow and the timing of nutrient loadings is essential to the development of models that predict nutrient loadings from tributary sources accurately.

Knowledge of the role of episodic events on deposition rates, fate, and transport of nonpoint source nutrient loadings is incomplete. Methods for obtaining quantitative data on rates and types of nutrient deposition during various atmospheric and climatic events would need to be developed to improve our understanding in this area. This may necessitate modification of traditional monitoring strategies.

Effect on Marine Ecosystems

Management Question 2: How do nutrient inputs affect marine ecosystems?

Information Needs

2a. Which nutrients limit primary productivity?

2b. How do nutrients affect productivity, function, and structure of marine ecosystems?

2a. Which nutrients limit primary productivity?

The question of which nutrients limit primary productivity is a central management concern. Mitigation policy can be formulated and implemented effectively only when environmental responses to changes in nutrient loadings can be predicted accurately. Of the macronutrients, phosphorus is the least abundant nutrient in the hydrosphere. Phosphorus is considered to be the limiting nutrient in many water bodies (Edmondson, 1972; Fuhs et al., 1972; Maloney et al., 1972; Powers et al., 1972; Schelske and Stoermer, 1972; GLWQB, 1987). Phytoplankton require nutrients in a ratio of about 16 nitrogen atoms for each phosphorus atom, which corresponds to their relative cellular composition of these elements. This ratio is known as the Redfield ratio. Nutrient-limiting environments contain nitrogen and phosphorus ratios either higher or lower than the Redfield ratio, depending on which nutrient is in shorter supply. Water column nitrogen concentrations are usually more than an order of magnitude greater than phosphorus concentrations in freshwater systems. Thus, biological demand for nitrogen and phosphorus in these systems will result in depletion of phosphorus before nitrogen. Under these conditions, phosphorus is the most effective agent both in promoting and in limiting freshwater primary productivity (Wetzel, 1975).

Regulatory agencies have used the principle of "phosphate limitation" by restricting the use of phosphate detergents and by limiting the allowable concentrations of phosphorus in effluents. Trends in water quality data and phytoplankton distribution and biomass demonstrate that management of phosphorus loadings has been successful in many freshwater bodies, including the Great Lakes (GLWQB, 1987) and Lake Washington, Washington State (Edmondson, 1972).

Researchers now debate whether nitrogen may be more important than phosphorus in controlling primary production in marine and estuarine waters (Smith, 1984; D'Elia, 1987). Nitrogen limitations in estuaries depend on factors other than relative concentrations of allochthonous nutrient inputs. Nutrient recycling and benthic-pelagic flux can influence greatly the relative amounts of biologically available nutrients. Studies by D'Elia (1987), Fisher and Doyle (1987), and Garber (1987) support the hypothesis that nitrogen is the limiting nutrient in the Chesapeake Bay. Studies by D'Elia indicate that much of the nitrogen entering the estuary is removed from the ecosystem by denitrification (conversion to nitrogen gas), while phosphorus is conserved in the ecosystem in the sediment. Fisher and Doyle (1987) found that recycling rates of nitrogen and phosphorus differed seasonally in a pattern that would support the theory of a phosphorus-limited system during the low-salinity conditions of spring and a nitrogen-limited system during higher-salinity summer conditions. Studies by Garber (1987) indicate that only a small amount of nitrogen input to the Chesapeake Bay becomes trapped in the sediment. Additionally, data on nutrient flux from sediment to overlaying waters indicate that there is an apparent loss of nitrogen relative to phosphorus in Chesapeake Bay sediments. There is also growing evidence that much of the allochthonous nutrient inputs to an estuary are eventually exported to the ocean (Nixon et al., 1986b).

To be able to distinguish among anthropogenic effects of nutrients in the marine environment, a better understanding of nutrient limitation and effects of nutrient inputs on phytoplankton populations is needed. Specifically, additional research to determine under what conditions phosphorus or nitrogen become the limiting nutrient in coastal, estuarine, and Great Lakes ecosystems is fundamental to this management question.

2b. How do nutrients affect productivity, function, and structure of marine ecosystems?

The response of an ecosystem to nutrient inputs depends on many factors, including the timing, amounts, and kinds of nutrient loadings, and the physical, climatic, and biological characteristics of the system. Excessive nutrient inputs accelerate eutrophication, causing increased phytoplankton blooms and biomass. Eutrophication also results in changes in phytoplankton species composition; in some instances, to "undesirable" or "nuisance" species which have less nutritional value or which are toxic (Gearing et al., 1984; Oviatt et al., 1984; Oviatt et al., 1986; Verity, 1987; Fulton and Paerl, 1987; Paerl, 1988a). High concentrations of nutrients also may exhibit direct toxicity to some organisms (Sullivan and Ritacco, 1985). Alterations in populations of primary producers have ramifications throughout the ecosystem by altering food webs (Grassle and Grassle, 1984; Grassle et al, 1985; Verity, 1987). One consequence of a large, inedible phytoplankton biomass is increased deposition of organic carbon (Rudnick and Oviatt, 1986), which may feed increased bacterial and micro-protozoan populations. Increased oxygen demand is another consequence (Hobbie and Cole, 1984). This microbial food web may shunt organic matter and energy away from commercially important species of fish and shellfish, and may contribute to development and maintenance of hypoxic and anoxic conditions (Verity, 1987).

Most current Federal programs that sponsor nutrient research include various aspects of research that address nutrient cycling and nutrient limitations. Research into global nutrient cycling and impacts of nutrients on distribution of phytoplankton is being carried out under NASA's Ocean Productivity Program and the NSF's Global Ocean Flux Program. The FWS is studying nutrient cycling in coastal marshes in its Research and Development Program. Under the USDA's Nonpoint Source Contaminants Program and Habitat Modification Program, the effects of agriculture, forestry, and watershed development activities and nutrient transformation in soils are being studied to understand nutrient dynamics, fates, and transformation. Mesocosm studies conducted by the EPA investigate the effects of nutrient loadings on estuaries. The EPA Great Lakes Program and Chesapeake Bay Program include research on the effects of nutrients on food web dynamics. NOAA's National Marine Sanctuary Program, Great Lakes Pollution Studies Program, National Fishery Ecology Program, and Sea Grant Ocean Pollution Program are all funding basic research into nutrient dynamics. Both the U.S. Army Corps of Engineers' Habitat Quality Program and the U.S. Department of Energy's Regional Marine Program address aspects of nutrient cycling.

Evidence has lead many researchers to believe that excessive anthropogenic nutrient inputs have harmed coastal ecosystems by altering the trophic structure. Confirmation of the extent of this problem will require quantitative data on both nutrient inputs and conditions of aquatic biota. The use of physical model ecosystems (e.g., mesocosms and microcosms) can contribute to our understanding of the dynamic relationships among nutrient inputs, primary *producers, and consumers. Extensive field research and monitoring also would be necessary if we are to determine the degree to which trophic structures already have changed and to determine effective mediation and mitigation procedures for restoring ecosystem health. This also will entail determining how reduced nutrient inputs will affect productivity of upper trophic-level organisms.*

Causes of Hypoxia and Anoxia

Management Question 3: What causes hypoxia and anoxia in coastal environments?

Information Need

3a. To what extent, and by what mechanisms, do nutrient inputs contribute to development and maintenance of hypoxic/anoxic conditions?

Important consequences of excessive nutrient loadings to a water body are hypoxia and anoxia. Data from mesocosm studies and from the Chesapeake Bay indicate that "increased primary productivity and elevated organic loadings of the water column and benthos stimulate microbial utilization of most or all of the available oxygen." (Verity, 1987). In the Chesapeake Bay, rapid development of hypoxia has been associated with decomposition of phytoplankton blooms coupled with increases in temperature and stratification (Magnien, 1987). Hypoxic conditions have been observed in a large number of U.S. coastal waters and estuaries (Whitledge, 1985). The susceptibility of a water body to hypoxia and anoxia may depend on physical characteristics of a basin in addition to anthropogenic nutrient loadings (Whitledge, 1985).

Considerable Federal research and monitoring is being conducted to understand and quantify the serious implications of hypoxia and anoxia to living resources. There are, however, some aspects of the problem where additional information would greatly enhance management's ability to mitigate the "greening" of the Nation's estuaries. Although it is accepted that allochthonous loadings of nutrients can lead to increased primary productivity, the quantitative relationship of allochthonous versus autochthonous inputs to eutrophication is not well understood. More accurate, precise, and applicable information would help to determine the role, in primary production, of external nutrient loadings and cycling of nutrients in the water column and across the sediment-water interface. The historical basis for whether incidences of hypoxia and anoxia have increased over time has not been resolved. This issue should be studied and resolved.

Adequacy of Analytical Methods

Management Question 4: Are conventional analytical methodologies adequate for nutrient research?

Information Need

4a. Are available analytical techniques sufficient for addressing nitrogen and phosphorus cycling in aquatic ecosystems?

Analytical methods are chosen to provide good historical comparisons, characterize baseline conditions, determine and predict trends in water quality, develop mathematical models and nutrient budgets, and identify important processes that affect water quality. However, the desire to maintain comparability with historical data and among various programs often institutionalizes "traditional" methods, even when they may be inadequate for addressing research needs. D'Elia et al. (1987) point out that "although comparability is clearly a valid concern, it can be argued that if historical methods are inadequate, then comparability is a moot point." Institutionalization of methodologies may have the additional effect of deterring development and use of more precise, accurate, and economical methods (D'Elia and Sanders, 1987; D'Elia et al., 1987). For example, D'Elia et al. (1987) found that direct determination of particulate nitrogen and phosphorus is significantly more precise, accurate, and inexpensive than the EPA-approved method of calculating the difference between whole and filtered water samples. Although the EPA method is sufficient for addressing problems of regulatory compliance with "end-of-pipe" water quality standards (the purpose for which the methods were chosen originally), it is not sufficiently accurate to analyze low concentrations of nutrients found in coastal waters.

Many standard methods for analyzing water quality and for measuring phytoplankton populations are inappropriate for research requirements. Often, where better methods exist, they are not widely used. A review of existing analytical procedures for sensitivity indicates that there is a general need for methods that are more accurate and precise. This is particularly true for fractional analysis nutrients, such as carbon, nitrogen, phosphorus, and silicon. Advances in this area would be necessary if we are to improve estimates of elemental standing stocks and budgets. Some review of analytical methods has been sponsored by EPA's Chesapeake Bay Program and Puget Sound Program. Recently, the Scientific and Technical Advisory Committee of the Chesapeake Bay Program (STAC, 1988) addressed this issue by recommending that the "evaluation and analysis of monitoring data and techniques to enable development of cost efficient, cost effective monitoring to support proposed strategies" be made a research priority in 1988. This and similar recommendations, as well as sponsorship of research and development of new and improved analytical methodologies for quantifying trace-level concentrations, would allow more effective research on nutrient cycling in aquatic ecosystems.

Conclusions and Recommendations

Excessive anthropogenic nutrient inputs have resulted in degradation of water quality and adverse effects on living marine resources in waters along all of the coasts of the United States. Anthropogenic nutrient inputs can cause accelerated eutrophication, which in turn can lead to hypoxic and anoxic conditions as well as alter food webs to favor less desirable species at higher trophic levels. Such conditions make these waters unsuitable as habitat for valuable living marine resources. Although much research has already been conducted on nutrient pollution, and several point sources of nutrients have come under increased control, many unanswered questions remain which would require a continued research effort on the part of the Federal Government to address. The following conclusions relating to our current state of knowledge concerning sources, fates, and effects of nutrients in aquatic environments are based on the discussions of management questions and information needs presented in the previous section.

- o Although we have much information on loadings from point sources of nutrients, we have very little information on the role of groundwater and atmospheric routes of input, and on the role of runoff during episodic events.

- o Although phosphorus appears to be the limiting nutrient in most freshwater systems, nutrient limitations in coastal and estuarine systems are not fully understood and may vary from place to place as well as seasonally.

- o Evidence exists to suggest that excessive anthropogenic nutrient inputs have altered the trophic structure of some coastal ecosystems.
- o The quantitative relationship between allochthonous (external) and autochthonous (recycled) nutrient sources to eutrophication and hypoxia and anoxia is not well understood.

- o Many current analytical methods for nutrients are inadequate, or if adequate, are not widely used.

Based on these conclusions, the following recommendations are made to improve our understanding of the sources, fates, and effects of nutrients entering the marine environment as a result of human activities.

Nutrient Sources

The following information is needed to improve our understanding of the role of various sources in nutrient loading.

Atmospheric and Groundwater Sources. As traditional point sources of nutrients are controlled, determining the mechanisms of loadings and quantifying nonpoint sources of nutrients need to be emphasized. To this end, additional research would allow us to determine the significance of atmospheric and groundwater sources of nutrients in estuaries and coastal areas.

Episodic Events. Research would help to determine the significance of seasonal runoff and aperiodic storms as sources of nutrients and their role in controlling the rates of production in marine ecosystems. Methods for gathering quantitative data on the rates of nutrient inputs during episodic events need to be developed.

Allochthonous versus Autochthonous Sources. Additional information would allow us to determine the role of allochthonous versus autochthonous nutrient inputs to a water body and the subsequent changes in water quality and ecosystem response.

System Response

The following work would improve our understanding of system-level response to excessive nutrient inputs.

Limiting Nutrients. Research is needed to determine the conditions under which either phosphorus or nitrogen limit primary productivity in coastal, estuarine, and Great Lakes ecosystems. Studies need to be conducted under various seasonal as well as physical and chemical conditions.

System Response to Eutrophication. Quantitative data on nutrient inputs and research on biotic response to nutrients are needed to understand the relationship between nutrient inputs, primary producers, and consumers. Such research should be designed to determine the degree of trophic structure changes resulting from excessive nutrient inputs.

Measurement Methodologies

The following work is needed to improve standard methods for conducting water quality analyses and for measuring phytoplankton populations.

Analytical Methods. The Federal Government should sponsor research into new and improved analytical methods that are both more accurate and precise for measuring nutrients and their effects in the marine environment.

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GOAL 3: UNDERSTAND THE SOURCES, FATES, AND EFFECTS ON MARINE ORGANISMS OF BIOLOGICAL AGENTS THAT ARE INTRODUCED OR INFLUENCED BY HUMAN ACTIVITIES

The presence of some biological agents in the marine environment may increase the incidence of various diseases among marine organisms, causing decreases in the population size or economic value of the affected species. Susceptibility of marine organisms to these biological agents may be increased as a result of pollution, and human activities may introduce, or induce the proliferation of, biological agents. The resources of concern include those that the Federal Government is mandated to protect, conserve, or manage such as marine mammals, fish and shellfish stocks, populations of endangered species, and ecologically important species or communities. Therefore, understanding the sources, fates, and effects of biological agents that are introduced or influenced by human activities is one of the six goals of the National Marine Pollution Program. This discussion focuses on microbial agents whose presence in the marine environment affects other marine organisms; human health effects are considered elsewhere in the Plan.

Goal Definition

For the purpose of this Plan, biological agents have been categorized as pathogens of marine organisms, toxic plankton, and introduced organisms. Known pathogens include bacteria, viruses, protozoans, and fungi. It is the presence and action of these agents within the tissues of affected organisms that cause an adverse impact. Toxic plankton are differentiated from pathogens by their mode of action; adverse effects may result through exposure to some toxin that is released by the plankton. Introduced organisms are organisms that do not occur naturally in the specific marine environment in question but have been introduced as a result of human activities. These include nonindigenous species and bioengineered organisms. Introduced species may be either macro- or microorganisms and may become pathogenic or toxic, or compete with indigenous species in their new environment. Macroorganisms may deleteriously affect the ecological balance by competing with indigenous species for resources such as space or nutrients, or through a more direct impact such as predation. The subject of introductions of macroorganisms is too broad to be addressed adequately within the context of this chapter; therefore, the discussion of introduced species will be limited primarily to microorganisms.

While the occurrence and action of some biological agents in the marine environment is known to be pollution-related, for others the link to pollution is only suspected, and all are clearly influenced by natural phenomena. Pollution may affect the action of a biological agent in two ways. A pathogen may be introduced or proliferate in the marine environment as a result of human activity. A concurrent increase in the incidence of disease among marine organisms may result from increased exposure to those agents. For example, the numbers of Vibrio anguillarum in the water column and sediment were shown to increase in the vicinity of a discharge of wastewater from a sugar plant (Colwell and Grimes, 1984). Alternately, environmental stresses caused by toxic chemicals in the water, or changes in salinity or temperature, for example, could increase the susceptibility of organisms to endemic opportunistic pathogens (Colwell and Grimes, 1984). Fin erosion in fish, infections caused by opportunistic Vibrio spp., bacterial hemorrhagic septicemia caused by Aeromonas spp. and Pseudomonas spp., and protozoan and fungal infestations (Costia necatrix and Saprolegnia spp.) are examples of secondary fish infections that occur when fish face environmental stresses (O'Connor et al., 1987; Sindermann, 1982; Wedermeyer et al., 1984).

Sources of Biological Agents

Biological agents can enter the marine environment directly as a result of human activities or exist naturally in the water column, sediments, or biota. In addition, some populations of agents may increase from a low level, which is normally sustained in the environment, to a higher level, which may impact other marine organisms. These increases in activity or blooms can be caused by human-induced alterations in environmental conditions. Also, some microbes may persist in the sediment in the form of cysts, becoming active when resuspended or ingested by the appropriate host organism.

Direct sources of biological agents resulting from land- or water-based human activities include:

- o Disposal of domestic, industrial, food preparation, and hospital wastes;
- o Runoff from feedlots, agricultural, or urban areas;

- o Accidental or deliberate inputs from research and educational laboratories;

- o Application of biological control agents;

- o Translocation of species through shipping activities, water ballast, and intentional transplanting;

- o Human flora introduction through recreational activities; and

- o Introductions associated with aquaculture and aquarium display.

Anthropogenic alterations to environmental conditions that may favor the redistribution and/or enhanced proliferation of biological agents include the following:

- o Environmental disturbances (dredging or shipping) resulting in resuspension and transport of sediments and sludges;

- o Changes in the physical environment, e.g., temperature (cooling water discharges), salinity, and turbidity (dredging); and

- o Changes in water chemistry through introduction of chemicals, e.g., nitrogen, phosphorus, and micronutrients.

Effects of Biological Agents

Table 5 is a list of examples of biological agents, their sources, human influence, resources affected, and impact. Some examples within the three groups of agents are discussed below, as well as diseases of unknown etiology and plasmid exchange.

Pathogens

Pathogenic organisms include but are not limited to bacteria, viruses, fungi, and protozoa. The presence of some pathogens may facilitate the action of secondary infections in marine organisms. Also, defense mechanisms of environmentally stressed marine organisms may be altered to such an extent that resistance to pathogens is lowered. Such interactions are exemplified by the increased mortality found among penaeid shrimp infected by baculovirus and suffering from environmentally induced stresses, generalized bacterial infections, or fouling organisms.

Leptospirosis, a disease associated with multiple hemorrhage syndrome in fur seals and sea lions, is an example of a disease caused by bacterial agents in the marine environment (Vedros et al., 1971; Smith et al., 1977). The causative agent of this disease, Leptospira spp., is most frequently acquired through the food chain by pups in their first year of pelagic existence (Smith et al., 1977). Environmental pollution, particularly the tissue accumulation of organochlorine and polychlorinated biphenyl compounds, is believed to increase the susceptibility of these animals to disease (Howard, 1984).

Table 5. Examples of Biological Agents, Their Sources, Human Influence, and Impact on Living Marine Resources

Category & Agent	Source	Human Influence	Resource Affected	Impact
PATHOGENS				
a) Bacteria				
Edwardsella tarda	unknown	unknown	fish, marine mammals	Hemmorrhagic disease in fish. Peritonitis. Opportunistic invader of sick and injured mammals. (Coles, et al., 1978)
Salmonella spp.	unknown	unknown	marine mammals	Juvenile mortality. Gulls aid in spreading disease (Gilmartin, et al., 1979)
Staphylococcus aureus *Staphylococcus equi*	unknown equine	unknown	dolphins, pilot whales, and other marine mammals	Cerebral abscesses resulting in strandings (Colgrove and Migaki, 1976). Brochopneumonia induced mortalities (Higgins, et al., 1980)
Leptospira spp.	indigenous	unknown	pinnepeds	Leptospirosis, multiple hemorrhage syndrome, strandings, mortality (Verdos et al., 1971; Smith et al., 1977)
Vibrio spp	indigenous	pollution stress enhances disease	fish, arthropods, mollusks	Red sore disease, ulcers, skin lesions, hemorrhage. Vibriosis generally affects stressed organisms (Colwell & Grimes 1984)
Beneckea spp *Pseudomonas spp* *Leucothrix spp*	indigenous	unknown	crustaceans	Shell disease, black spot disease. Disease enhanced by high temperature and crowding
b) Viruses				
Adenovirus	unknown	environmental stress enhances disease	fish	Epithelial hyperplasias (Bloch et al., 1986)
Influenza A	human	unknown	marine mammals	strandings, mortalities (Hindshaw et al., 1986 (Geraci et al., 1982)
Baculoviridae Herpesviridae	unknown	enhanced by environmental	mollusks crustaceans	Mortality
Iridoviridae Papovaviridae	mammalian unknown	enhanced by environmental	mollusks, fish mollusks	Mortality associated with neoplasms (Johnson 1984)
Calicivirus	indigenous to Pacific	unknown	pinnipeds fish	Premature partuition
c) Fungi				
Ichthyophonus spp *Blastomyces spp* *Lagenidium spp* *Fusarium spp*	indigenous unknown indigenous unknown	dredging, resuspension, stress shrimp, sharks	fish marine mammals shrimp	Mortality Dermatitis, systemic infections, mortality
TOXIC PLANKTON				
Dinoflagellates Raphidophytes Prymnesiophytes Nonflagellated red algae Cyanobacteria	indigenous	blooms are enhanced by nutrient inputs	shellfish fish, and marine mammals	Concentrate in shellfish cause mortalities in shellfish, fish, marine mammals. Produce anoxic conditions resulting in fish kills.
INTRODUCED ORGANISMS				
Mytillecula orientalis (Copepod parasite)	Japan	introduced with Japanese seed oysters	oysters & mollusks	Substantial reduction in shellfish stocks, commercial exploitation of oyster grounds abandoned
Minchinia nelsoni (protozoan)	unknown	incidence spread on East coast with contaminated shipments	oysters	Causative agent of MSX. Destruction of many oyster grounds.

Bacteria of the genus Vibrio are ubiquitous in the marine environment. Characteristics of fish diseases caused by Vibrio spp. include skin lesions and ulcers. Outbreaks of Vibriosis are generally attributable to some form of environmental stress or exposure to metal contamination, which increases the susceptibility of the fish to the disease (Colwell and Grimes, 1984). A high correlation between the occurrence of V. anguillarum in fish and contamination by wastewater discharges has been observed (Larsen et al., 1978). In addition, significantly higher concentrations of antibodies to V. anguillarum were observed in flounder collected from the New York Bight apex than in flounder from unpolluted coastal waters (Robohm et al., 1979).

Viruses may affect a variety of marine fish (Bloch et al., 1986) and shellfish (Couch, 1978). Type A Influenza virus is an example of a human pathogen which has been implicated in mortalities of harbour seals and pilot whales (Murphy et al., 1983; Geraci et al., 1982; 1983; Hinshaw et al., 1986). Influenza A viruses found in whales in one study were believed to be dispersed in seagull feces (Geraci et al., 1983).

Human influence on the incidence of fungal diseases of marine organisms is not well documented; however, the following are examples of fungi that have impacted living marine resources. Blastomyces is a fungus found in dolphins and sea lions. This atypical yeast is an opportunistic invader of compromised marine mammals, and may cause fatal systemic or respiratory disease. Members of the genus Ichthyophonus are the major fungal agents that cause dermal disorders in marine finfish. Fungi of the genera Lagenidium and Fusarium are responsible for diseases in penaeid shrimp (Couch, 1978).

Protozoa represent a group of pathogens that have been responsible for major impacts to economically important marine resources. Multinucleated sphere unknown (MSX) is probably one of the most devastating epizootic diseases to affect marine resources reported in the United States. The organism responsible for MSX outbreaks is the protozoan Haplosporidium nelsoni. This disease has devastated the oyster industry on the east coast of the United States, causing mortalities of up to 90% of the population in some localities. Severe mortalities of oysters were first observed in the Delaware Bay in 1957, and in the lower Chesapeake Bay in 1960. MSX was probably spread to Massachusetts with shipments of infected oysters from the James River in Virginia (Rosenfield and Kern, 1978). The spread and severity of H. nelsoni is related to high salinity, mortalities being observed most often in waters of $\geq$ 15 ppt (Rosenfield and Kern, 1978). Human-influenced alterations in freshwater movement in estuaries have contributed to the upstream spread of this disease.

Toxic Plankton Blooms

Toxic plankton cause deleterious effects by releasing toxins into the environment as well as by depleting oxygen in waters where blooms occur. Toxic plankton belong to a few groups; the majority are dinoflagellates, while the rest are chloromonads (Raphidophytes), Prymnesiophytes (nonflagellated red algae), and cyanobacteria (blue-green algae) (Taylor, 1985).

Toxic plankton blooms have been correlated with freshwater influxes and certain temperature regimes (Therriault et al., 1985). Increased frequencies of blooms may be associated with growing industrialization and associated nutrient inputs into affected waters (MacLean and White, 1985).

The accumulation of dinoflagellate toxins in bivalves has resulted in the closure of shellfish beds. In addition, toxic plankton blooms have been implicated in fish and marine mammal mortalities. Recently, toxic plankton have destroyed scallop beds in North Carolina and fish populations off the coast of Texas. Blooms of Prymnesium calathiferum have coincided with fish and shellfish mortalities in New Zealand (Chang, 1985). Massive fish mortalities in the Faroe Islands have been caused by Gonyaulax excavata red tides (Mortensen, 1985).

Introduced Organisms

Introduced organisms do not exist naturally in a specific marine environment or region, but occur as a result of human activities. These organisms include nonindigenous species and bioengineered organisms. Introduced organisms may be pathogens, parasites, toxic plankton, predators, or competitors and thereby exert a negative influence on indigenous populations.

The inadvertent introduction of infectious disease-causing agents carried with intentionally introduced species exemplifies the problems caused by the movement of organisms to new areas. The careless transfer of diseased oyster stocks into previously disease-free areas is responsible for adverse impacts on existing biota. For example, the spread of MSX was probably aided by the transfer of infected oysters from the Chesapeake Bay to Massachusetts (Rosenfield and Kern, 1978). In addition, toxic plankton inoculates and other pathogenic organisms have the potential to be introduced with cultures of marine organisms.

The introduction of bioengineered organisms has not yet been permitted in the marine environment. However, bioengineered organisms released on land may persist and be transported to the sea. Recent evidence suggests that genetically engineered organisms may persist in the marine environment longer than previously believed (Colwell et al., 1985), and eventually impact living marine resources.

Another concern is the effect that novel, nonbioengineered organisms released in artificially high densities for the control of one species could have on related nontarget species. For example, the possibility exists that a bacterium or virus targeted at insect populations could be transported to the marine environment and infect marine arthropod species such as shrimp, crabs, and lobster (Rosenfield, 1988).

Diseases of Unknown Etiology and Plasmid Exchange

There are many cases of diseases where the impact on marine resources has been severe, but where the etiology is unknown. The recent increase in the incidence of bottlenose dolphin and whale beachings along the east coast of the United States and the Gulf of St. Lawrence has aroused interest in determining whether human influence is involved in this phenomenon. Biological agents are one of the suspected causes of these beachings.

Neoplasms present a serious problem affecting the softshell clam industry. Neoplasms in the clam Mya arenaria were first observed in England by Yevich and Barszcz (1976) and later were found in the clams of the Chesapeake Bay (Farley, 1978). Neoplasms are now present in 50 to 60% of the clams sampled in the bay. The occurrence of neoplasms is enhanced when clams face natural environmental stresses such as changes in temperature and salinity (Sindermann, 1982). A viral etiology is suspected, but remains unproven (Sindermann, 1982). Also, the exact influence of pollution is not known.

The coral reef environment has recently been subject to damage of unknown causes. In 1982, and again in 1987, scleratinian corals in many areas of the Caribbean, Bahamas, and Florida were affected by a bleaching disease resulting from loss of zooxanthellae. Zooxanthellae are algal cells that exist symbiotically and aid in the biological functions of coral tissue. The synchronicity of bleaching events throughout the Caribbean has raised concern that some biological agent may be involved in this disease (Roberts, 1988). In 1983, mass mortalities of the black sea urchin resulted in the virtual disappearance of this ecologically important species from coral reefs in the Caribbean basin. No cause has been discovered for this phenomenon (Williams and Williams, 1987).

Plasmid exchange is also an area of concern. This process, which involves the transfer of genes from one microorganism to another, may confer certain undesirable characteristics to a previously benign agent. Plasmid exchange has the potential of creating virulence or resistance to antibiotics in microorganisms (McConnell et al., 1979). Plasmid exchange could result in the creation of novel forms in a process similar to genetic engineering. The development of resistance to antibiotics by certain pathogenic organisms exposed to outflows or antibiotic dumps has been demonstrated for bacteria associated with mammals (Flint et al., 1987; Wachsmuth et al., 1983). Such novel strains may defy attempts to control their spread and mitigate impact on marine resources.

Federal Role

The Federal legislation, regulations, and programs that address the issue of the sources, fates, and effects of biological agents in the marine environment are discussed in this section. Additional discussions of Federal programs as related to specific information needs are presented under the management questions that follow this review of the Federal role. More detailed information on the Federal programs and projects that address the issue of biological agents in the marine environment can be found in the National Marine Pollution Program, Summary of Federal Programs and Projects (NOAA, 1987).

Federal Legislation and Regulations

The major Federal legislative mandates relating to discharges into marine waters that potentially affect or contain biological agents are the Federal Water Pollution Control Act, as amended (FWPCA, or Clean Water Act), and the Marine Protection, Research, and Sanctuaries Act (MPRSA). These Acts regulate and require research and monitoring to assess impacts from such discharges.

The FWPCA represents the most comprehensive statute regulating marine pollution. Under the FWPCA the term contaminant includes biological substances that may be in the material proposed for discharge. The stated goal of the FWPCA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Section 402 of the Act establishes the National Pollutant Discharge Elimination System (NPDES) Program to control point source discharges into the nation's surface waters. Under this program dischargers are required to disclose the nature and volume of their discharges, and to restore and maintain the quality of these waters. The EPA is authorized to specify limitations to be imposed on such dischargers, and requires the dischargers to monitor and report their compliance with the limitations. In addition, under Section 403(c), EPA is required to establish ocean discharge criteria guidelines for determining unreasonable degradation prior to the issuance of permits. Under Section 104 of the FWPCA, EPA is to cooperate with other Federal, state, and local agencies to conduct and promote the coordination of research "...relating to the causes, effects, extent, prevention, reduction, and elimination of pollution..." Section 403 of the Act authorizes EPA to assess the impact of a discharge on both the biological community in the area of the discharge and on surrounding biological communities.

The Water Quality Act (1987 amendments to FWPCA) establishes a national program for the control of nonpoint sources of pollution. Under Section 316 of the Act, states are required to identify the sources of nonpoint pollution that significantly contribute to pollution in their waters, and describe their programs for controlling such sources.

Title I of the MPRSA provides for the regulation of ocean dumping of municipal and industrial wastes, and dredged material in U.S. waters through the issuance of permits by EPA and the U.S. Army Corps of Engineers for dredged material. Ocean dumping permit reviews are based on several criteria including:

- The effect of dumping on human health and welfare;
- The effect of dumping on marine ecosystems, particularly with respect to the transfer, concentration, and dispersion of material and byproducts through biological, physical, and chemical processes; potential changes in marine ecosystem diversity, productivity and stability; and species and community population dynamics;
- The persistence of the effects of dumping; and
- The appropriate location and method of disposal.

Title II of the MPRSA establishes a comprehensive monitoring and research program on the effects of ocean dumping and long-term effects of pollution, overfishing, and man-induced changes to the marine environment. This program includes assessment of the environment's capacity to receive materials, and monitoring programs to assess the health of the marine environment.

Various legislative mandates have been implemented to manage, protect, and conserve living marine resources and often relate to impacts from marine pollution. Living marine resources considered under these mandates include endangered species, marine mammals, and ecologically and economically important marine species. Biological agents are included under definitions of waste constituents that may endanger living marine resources. The major Federal legislative mandates governing the management, protection, and conservation of living marine resources potentially impacted by biological agents include the Endangered Species Act, Marine Mammal Protection Act, Magnuson Fishery Conservation and Management Act (Magnuson Act), and the Whale Conservation and Protection Study Act. NOAA has been given management and conservation responsibilities under each of these acts, while FWS is responsible for certain species under the Endangered Species Act and the Marine Mammal Protection Act.

Federal Programs

The research funded by the Federal Government concerning biological agents has generally not been directed specifically to effects on marine organisms. Most of this research relates to human health concerns; therefore, much of it has not been very effective in addressing problem areas associated with the effects of agents on marine biota.

NOAA, EPA, and FDA have funded the majority of Federal research on biological agents. Within NOAA, these activities are conducted by the National Marine Fisheries Service (NMFS); the Sea Grant Program of the Office of Oceanic and Atmospheric Research (OAR); and the Coastal and Estuarine Assessments Branch, Strategic Assessments Branch, and National Marine Sanctuaries Program of the National Ocean Service. These NOAA offices perform studies related to biological agents as part of the NOAA mandates to establish a comprehensive and continuing program of monitoring and research with respect to the effects of pollution and to manage and protect living marine resources. Studies include monitoring the occurrence of pathogens and incidence of tissue lesions and other abnormalities in living marine resources, and research into the causes of diseases and death among marine mammals, finfish, and shellfish. The agency develops techniques for determining the fate of sewage discharges and for detecting, identifying, and measuring biological agents in the marine environment. NOAA also maintains an inventory of the extent and status of shellfish areas in U.S. waters and compiles historical health data on estuarine shellfish areas.

Much of the research conducted by EPA that is directly related to the potential impacts of biological agents on the marine environment is performed at the agency's Environmental Research Laboratory in Gulf Breeze, Florida. Research conducted at this facility includes the development and laboratory testing of methods and procedures to determine the pathogenicity or toxicity of biological control agents to nontarget organisms and the assessment of potential ecological risk to the environment associated with the application of genetically engineered organisms. The EPA also conducts related research at its other environmental research laboratories, such as the Narragansett, Rhode Island laboratory, and supports studies related to biological agents through its National Estuary Program.

The FDA conducts extensive research on pathogens and other environmental hazards associated with fisheries products. While much of the research is oriented toward public health concerns, a significant amount deals with the identification of pathogens and deleterious materials, mechanisms of pathogenicity, and incidence and levels of contamination of estuarine samples with bacterial and viral pathogens, parasites, toxic plankton, and chemical hazards. In addition, the FDA maintains three regional laboratories dedicated solely to fisheries research and fisheries-related activities.

Although it is not a major supporter of studies concerned with the effects of biological agents in the marine environment, the U.S. Department of Energy (DOE) has funded related research. Specifically, DOE has investigated the increased susceptibility of marine organisms to infectious diseases when stressed by pollutants. The FWS and the U.S. Department of Agriculture also conduct some research activities related to biological agents in the marine environment.

Management Questions and Information Needs

Human-influenced or -introduced biological agents and their impact on living marine resources have received relatively little attention in the past as compared to other forms of pollution, such as toxic chemical discharges and nutrient enrichment. In many cases, diseases in populations of marine organisms have been observed that are suspected of being caused by biological agents, but evidence linking the agent to the disease is lacking or incomplete. Four management questions that need to be addressed to achieve the goal of understanding the sources, fates, and effects of biological agents that have been introduced or influenced by human activities in the marine environment are listed below. This section includes a discussion of the rationale, current efforts, and remaining work associated with the information needs for each management question.

Management Question 1: What problems are known or suspected to result from human influence on, or introduction of, biological agents in the marine environment?

Management Question 2: What are the biological characteristics, environmental requirements, and mechanisms of pathogenicity of the most significant biological agents?

Management Question 3: What are the sources and mechanisms of human influence on biological agents in the marine environment?

Management Question 4: How can acute and chronic problems associated with biological agents be predicted, controlled, and mitigated?

Problems Associated with Biological Agents

Management Question 1: What problems are known or suspected to result from human influence on, or introduction of, biological agents in the marine environment?

Information Needs

1a. What are the major concerns associated with pathogens?

1b. To what extent does pollution cause toxic plankton blooms, and what are the resulting economically important fishery concerns?

1c. What are the effects of the introduction of nonindigenous species or bioengineered organisms?

1a. What are the major concerns associated with pathogens?

Much evidence exists to suggest that human influences on pathogens in the marine environment may present a significant threat to valuable living marine resources. This information has been summarized in the Goal Definition section above.

While research efforts sponsored by Federal agencies are primarily concerned with the human health impacts of pathogens in the marine environment, some of these studies may also apply to the effects of pathogens on marine resources. Such studies have been conducted through the National Marine Fisheries Service (NMFS) of NOAA, the FWS, and the FDA. The role of infectious disease in population dynamics of commercial and recreational marine species is the subject of studies by NMFS and FWS. Research conducted by FDA has attempted to determine the incidence and pathogenicity of various microbial agents in shellfish, fish, and marine water.

The effects of some pathogens on living marine resources are known. However, while problems caused by pathogens may be apparent, the identification of the specific pathogenic organisms involved, the processes that increase their pathogenicity, the host ranges, and predictions of outbreaks are not as easily determined. The research necessary to address these areas includes the development of rapid, inexpensive, and easy-to-use systems for the detection, isolation, characterization, and quantification of pathogens that cause disease among marine organisms.

1b. To what extent does pollution cause toxic plankton blooms, and what are the resulting economically important fishery concerns?

Toxic plankton blooms have been implicated in the closure and destruction of shellfish beds, declines in fish populations, and the death of marine mammals. Freshwater influxes and certain temperature regimes have been partially correlated with toxic plankton blooms (Therriault et al., 1985); however, other factors, including pollution, may be involved. Many areas that historically have had little evidence of such blooms have recently shown increasing occurrences. This increase has been associated with growing industrialization and nutrient inputs into the affected waters (MacLean and White, 1985).

The exact mechanisms and factors responsible for toxic plankton blooms have yet to be determined. Human health concerns are the motivating factor for addressing problems associated with toxic plankton bloom in research projects funded through the Sea Grant Office of NOAA. The Florida Department of Natural Resources in cooperation with NOAA supports research to determine the life history of Ptychodiscus brevis, the factors which trigger red tides, and the development of rapid techniques for the determination of dinoflagellate toxins in fish and shellfish.

Additional problems are the identification of organisms involved, determination of toxicity and toxin production by microbial forms, and the range of organisms affected by such toxins. The FDA sponsors studies that both address the problem of toxicity of dinoflagellate toxins to humans and attempt to determine the incidence and levels of algal toxins contained in fish and shellfish.

Major gaps exist in our understanding of the causal mechanisms of toxic plankton blooms. While pollution is believed to play a role in such periodic events, the exact mechanisms that trigger blooms and the environmental requirements of toxic plankton species are not well known. Understanding the factors that cause toxic plankton blooms is a necessary first step in the development of measures to control or limit their impact.

1c. What are the effects of the introduction of nonindigenous species or bioengineered organisms?

A large proportion of the biological agents responsible for adverse effects on marine resources have been artificially introduced, either by accident or intentionally. Not all species introduced to new areas are injurious or harmful to resident biota. The deliberate introductions of some desired species have been beneficial to man. In other cases, introductions of nonindigenous species have caused serious ecological damage. Examples of problems resulting from the movement of species to new areas include introductions of infectious disease-causing agents or toxic plankton organisms along with seed oysters or other species used for aquaculture.

Environmental introductions of genetically manipulated animals and microorganisms are commonplace (CEQ, 1985). Such organisms have historically been a major thrust of agricultural developments designed to improve the characteristics of crops and livestock. While there is a vast experience with environmental introductions of genetically engineered organisms such as plants and animals, there has been less experience with the release of genetically engineered microorganisms. Concern has been raised that novel strains of various organisms may some day pose a threat to marine resources. Bioengineered microorganisms can be viewed in the same light as nonindigenous naturally occurring organisms with regard to their introduction into the marine environment. In either case, living marine resources may lack mechanisms of resistance or defense against the effects of the introduced organisms. Such biological agents may proliferate and cause extensive damage to indigenous populations.

The Biotechnology Science Coordinating Committee (BSCC) was established by the Federal Government in 1985 to address the issues of research and products of biotechnology by providing a coordinated framework of scientific policy and scientific review. The BSCC has recommended that more intense scientific review be given to organisms that are the product of intergenetic combinations and combinations involving genetic material from pathogenic organisms.

Research in subjects concerned with the survival and effects of genetically engineered organisms in the marine environment is still in its infancy. Much of this research is sponsored by EPA's Environmental Research Laboratory in Gulf Breeze, Florida. Projects include the determination of growth potential of bacteria that may be used in genetic engineering, determination of the impact of genetically altered microorganisms on the environment, development of simple laboratory procedures for predicting survival and growth of bacteria in natural environments, and development of methods for detecting and tracking genetically engineered microorganisms in aquatic environments.

There appears to be a lack of research associated with introductions of organisms into the marine environment. The NMFS-sponsored studies include a description of species introduced to the United States Pacific and Atlantic Coasts in ballast water from ocean-going vessels, and the histological examination of foreign shellfish imports to the United States.

The potential effects of introductions of nonindigenous species or recombinant forms presents a concern that should be addressed more fully. To accomplish this, each introduction, whether of an organism that is indigenous to other geographical areas or a bioengineered microorganism, should be evaluated on an individual basis prior to its release as *to its potential effects on existing populations. In addition, further research into the effects on nontarget marine biota of persistent nonendemic organisms introduced as pest control agents would improve our understanding in this area.*

Characteristics, Requirements, and Mechanisms of Pathogenicity

Management Question 2: What are the biological characteristics, environmental requirements, and mechanisms of pathogenicity of the most significant biological agents?

Information Needs

2a. What are the basic biological attributes of biological agents known to adversely affect marine organisms?

2b. What are the mechanisms by which biological agents cause disease in marine organisms?

2a. What are the basic biological attributes of biological agents known to adversely affect marine organisms?

To mitigate the effects of biological agents on valuable marine resources, researchers must develop an understanding of the biological characteristics and environmental requirements of the biological agents that impact these resources. There is a general lack of knowledge of basic biology, life cycles, life history, and environmental requirements of the organisms of concern.

Past studies that address the question of basic attributes of biological agents generally have been concerned with those agents that may impact human health. Such studies are being conducted by NOAA (OAR and NMFS), EPA, and FDA. The Office of Oceanic and Atmospheric Research in NOAA sponsors studies that address the identification and characterization of pathogens or toxins produced by biological agents. The NMFS conducts and sponsors studies of infectious crustacean diseases and parasites in west coast species, histopathological studies of infectious molluscan diseases and parasites, and the immunological identification of shellfish pathogens and life history stages in alternate and reservoir hosts. The EPA conducts and sponsors studies that evaluate the occurrence and extent of gene transfers, plasmid transmissibility, and mechanisms of dissemination of recombinant DNA in aquatic environments. The FDA-sponsored studies include the development of culture systems for algal toxin production, chemical and biological definition of dinoflagellate toxins, and genetic characterization of Vibrio and Aeromona species.

In order to gain a better understanding of the impact of biological agents, basic information is needed on the biological attributes of a wide range of such agents found in the marine environment. For example, while a causative agent of disease in oysters has been identified as H. nelsoni, it has not been successfully cultured in the laboratory. An intermediate host is suspected in this parasite's life history, but none has yet been identified. Some basic questions on taxonomy remain to be answered for various groups of pathogenic organisms, including Vibrio species, marine fungi, and protozoa. In addition, the pathogenic *mechanisms, host ranges, and persistence of a wide variety of organisms that normally inhabit the human intestinal tract or the marine environment are unknown and require further research.*

<u>2b. What are the mechanisms by which biological agents cause disease in marine organisms</u>?

Pathogens may be absorbed by marine organisms through contact, ingestion, or transmission via intermediate hosts. A pathogen may then affect the host organism by producing toxins, causing the growth of tumors, disrupting metabolic pathways or reproductive processes, or by causing behavioral alterations. A thorough understanding of the biophysical and biochemical mechanisms of pathogenicity, host specificity, immunity, and means of transmission of the important diseases is necessary prior to attempting to mitigate the impacts that various biological agents may have on marine resources.

The subject of pathogenic mechanisms is being addressed in studies sponsored by NMFS and FDA. Shellfish disease resistance and defense mechanisms in marine mollusks, and disease diagnostics and immune responses among Pacific Coast salmonid fish species are being investigated by NMFS scientists. Studies funded by FDA are directed towards human health aspects of the issue, and include the evaluation of the pathogenesis of <u>Aeromonas</u> and <u>Vibrio</u> species and the evaluation of virulence of various pathogens in marine waters.

A major factor limiting studies of virulence of invertebrate viruses is the lack of molluscan and crustacean cell and tissue culture systems. The development of <u>in vitro</u> and <u>in vivo</u> cultivation systems for growth of microbial agents could be used for qualitative and quantitative studies of dose response infectivity, disease transmission mechanisms, cell cycle studies, inactivation mechanisms, and for the demonstration of cause and effect relationships. Such systems have been developed for mammalian and insect cells and greatly facilitate this sort of studies.

Sources of Human Influence

<u>Management Question 3: What are the sources and mechanisms of human influence on biological agents in the marine environment</u>?

Information Needs

3a. What are the sources of the most significant biological agents?

3b. What are the persistence and transport mechanisms of these agents?

<u>3a. What are the sources of the most significant biological agents</u>?

Biological agents are released into the marine environment from a variety of terrestrial sources. In addition, human activities such as dredging or sewage discharges may affect population densities of marine microorganisms. Pollution may cause the proliferation of certain pathogenic agents that are normally present at low densities. Knowledge of the types and locations of inputs of biological agents into the marine environment would aid in development of an effective control or mitigation strategy. Although potential sources of biological agents are known, it is difficult to quantitatively determine the extent to which pathogens are being introduced from point and nonpoint sources.

Research related to sources of biological agents is being funded by NOAA and FDA. Human health concerns have motivated NOAA to initiate a project to determine the basis for shellfish harvesting limitations in estuaries around the Nation and to identify sources of pollution in those estuaries where harvest limitations are due to pathogens. The NMFS of NOAA is sponsoring studies under the Northeast Fisheries Center's Inshore Research Plan to determine the relationship between pathogen outbreaks and other sources of organism stress, such as contaminants, nutrient overenrichment, and habitat loss. The FDA sponsors studies into subjects such as the occurrence of drug and antibiotic resistance in natural flora, the potential for transferring resistance to bacterial species that are human pathogens, and the drug resistance of human pathogens present in fish, water, and sediment.

Studies to identify the sources of biological agents and to quantify the relative and absolute amounts of these materials coming from various sources would generate useful information. In addition, the development of a global information network and newsletter to notify the scientific community of biological invasions of nonindigenous microbial agents or macroorganisms into marine ecosystems through man's activities or through natural mechanisms would assist in addressing this information gap.

<u>3b. What are the persistence and transport mechanisms of these agents</u>?

Some biological agents are maintained in an inactive state in the sediment, water column, or biological component of the marine environment for months or longer (OTA, 1987). These agents may be activated by changes in environmental conditions such as resuspension of sediments followed by exposure to suitable hosts or growth substrates, or nutrient inputs. In other cases, ubiquitous, normally commensal agents may become virulent to host organisms that face environmental stresses. Episodic events such as storms, floods, or hurricanes may resuspend pathogen spores or germ cells along with sediment. The relative importance of such natural events needs to be evaluated to understand the impact of human activities on the system.

Some studies related to the persistence and transport of biological agents in the marine environment are being conducted by EPA, NOAA, NMFS, and the Florida Department of Natural Resources. The fate of new genotypes and the factors that influence the survival of recombinant microorganisms are the subjects of studies sponsored by EPA. NOAA's Sea Grant Program and Estuarine Program Office address the question of mechanisms of survival and transport of enteric viruses and other human pathogens in estuarine environments. The NMFS sponsors studies of the clearance of haplosporidia parasites from oysters under controlled salinity and temperature and on disease resistance. Related studies conducted at the NMFS Northeast Fisheries Center attempt to identify the conditions that favor pathogen productivity and movement, intermediate hosts, ranges, and transport media for pathogens. The Florida Department of Natural Resources is investigating the persistence and factors that reactivate dinoflagellate spores present in water and sediment.

The implementation of control or eradication procedures, and the prediction of outbreaks of disease among marine organisms, require an understanding of the transport mechanisms and persistence of biological agents in the marine environment and in biological systems. It would *be useful to develop an understanding of the fate of agents in the marine environment, and the mode of transport, persistence, and concentration of these organisms or toxins through the food chain. This knowledge will significantly improve the capability to predict the consequences of human activities, and enhance the ability to cope with disease outbreaks.*

Prediction, Control, and Mitigation

Management Question 4: How can acute and chronic problems associated with biological agents be predicted, controlled, and mitigated?

Information Needs

4a. What contingency plans can be developed to study episodic events?

4b. What strategies can be developed for mitigation of effects of biological agents?

4a. What contingency plans can be developed to study episodic events?

Mass mortalities and disease outbreaks in the marine environment appear as sudden episodic events that have the ability to impact a system before they can be controlled. Recent episodic events have included the bottlenose dolphin beachings off the east coast of the United States in 1987, mass mortalities of sea urchins in the Caribbean Basin in 1983, and coral bleaching incidents in 1982-83 and 1987-88. Mass mortalities of commercially important species such as herring, striped bass, blue crab, menhaden, and king crab have also been reported (Rosenfield, 1988). The conditions that have resulted in such events are not well documented and extremely unpredictable. Information associated with aperiodic events can only be obtained if appropriate contingency plans are developed and responses can be implemented in a timely fashion.

Long-term monitoring of problems related to biological agents may aid in the identification of aperiodic events as they occur. An attempt at such monitoring currently proposed by NMFS includes a registry for marine pathology, and the development of a national shellfish health and protection plan. Related activities conducted by NOAA include the collection and analysis of bottom-feeding fish for diseases under the National Status and Trends Program. In addition, the Florida Department of Natural Resources and NOAA are using satellite imagery techniques in an attempt to predict conditions that result in blooms of red tide.

The study of episodic outbreaks such as toxic plankton blooms and marine mammal beachings is needed to learn about the causes of these events and possibly their eventual control. The implementation of a computerized system for cataloging and managing data on disease agents and pathways manifested by geographic location and other factors in fish, shellfish, marine mammals, and other marine organisms in North American marine and estuarine waters, which is associated with a literature search program, would assist in making such data available to the scientific community.

A major difficulty in the study of aperiodic events is their lack of predictability. Williams and Williams (1987) suggested the establishment of an alert and communications center for early detection of episodic events. A network of on-call scientists could be *established to support the functioning of such a center. While early warning, confirmation, and expert analysis and documentation will not stop episodic events, this kind of system is believed to be a practical step toward determining causes for each event, and providing a baseline for the more complicated goals of managing and mitigating the adverse effects of biological agents.*

4b. What strategies can be developed for mitigation of effects of biological agents?

The impact of biological agents on marine resources results from two factors: an increased pathogenicity on the part of the agent, or a decreased resistance on the part of the host. Major problems stem from the intentional or accidental introduction of biological agents into a biologically important area. These introductions, which may be novel forms to the region, will result in a lack of resistance by the indigenous populations. A second concern is the effect of human activities and resulting environmental stresses faced by marine organisms in a degraded environment where the increase in numbers of pathogenic organisms is favored or where the resistance of existing species to the ubiquitous pathogens is decreased.

Basic research may result in the development of measures to mitigate the effects of biological agents. While such research in the past generally addressed human health concerns, the results of these studies may be applicable to effects of biological agents on marine organisms. For example, FDA conducts research on methods for quantification of viruses in shellfish, detection of parasites in scallops, and detection and quantification of algal toxins. NOAA Sea Grant funds research into the assessment and control of hepatitis A virus contamination of shellfish, and pathogens in mangrove oysters.

The introduction of pathogenic organisms and species detrimental to the marine environment must ultimately be reduced at the source by controlling inputs from land-based sources, by properly evaluating species targeted for introduction prior to release, and by limiting unintentional inputs of detrimental organisms associated with the species targeted for introduction. Such approaches have been implemented at the quarantine facility in Conway, Wales, where a central laboratory has been established for the evaluation of the potential effects of all organisms prior to their release into the marine environment. All organisms are classified according to their potential for pathogenicity and ecological damage. Later generations of these laboratory-bred organisms are released only after it has been determined that they will not threaten the indigenous biota (Sindermann, 1988).

Mitigating the effects of biological agents that are already present in the marine environment presents a difficult problem. Reduction or elimination of environmental stresses on the biota is necessary. This can only be achieved by reductions of pollutant loadings and other environmental stressors. The determination of which factors cause stress responses would be a first step in researching the means of combatting this problem.

Conclusions and Recommendations

The subject of human-influenced biological agents that affect marine organisms has been largely neglected in the past. Most research has been directed toward human health concerns. The current base of knowledge on effects of biological agents is primarily observational, including observations from monitoring programs and the characterization of sporadic incidents.

GOALS OF THE NATIONAL PROGRAM

The following conclusions relating to the current state of knowledge concerning sources, fates, and effects of biological agents in the marine environment are based on the discussion of management questions and information needs presented in the previous section.

- For many outbreaks of disease and mass mortalities of living marine resources, we do not know the specific biological agent responsible or the mechanism of impact. In some cases, biological agents may be introduced to the marine environment as a result of human activities. In other cases, pollution may cause stress in marine organisms, thereby making them more susceptible to infection by biological agents;

- The basic biological attributes of many biological agents, such as life history, environmental requirements, taxonomy, and persistence in the marine environment are unknown;

- The importance of natural events and human activities and the environmental conditions necessary for the occurrence of mass mortalities and disease outbreaks in living marine resources are often not understood; and

- Very little is known concerning the survival and effects of genetically engineered organisms in the marine environment.

Research approaches directed towards problems that are caused by biological agents can be divided into four categories based on the current level of knowledge. Each category requires a specific approach to attain most efficiently the necessary level of knowledge concerning the diseases that are suspected or known to be caused by biological agents. These categories of research approach are:

1. Observed events where biological agents are suspected, but for which there is no understanding of the cause;

2. Biological agents that are suspected to affect marine organisms, but evidence of such an effect is lacking;

3. Biological agents known to affect marine organisms, but where the knowledge of the impact is incomplete; and

4. Biological agents that are known to affect marine organisms, and where knowledge of the impact is adequate, but whose action cannot yet be mitigated.

A conventional procedure for determining the etiology of a bacterial disease is to prove Koch's postulates. These postulates are:

1. The pathogen should always be found in animals suffering from the disease, and should not be present in healthy individuals.

2. The pathogen must be cultivated in pure culture away from the animal body.

3. Such a culture, when inoculated into susceptible animals, should initiate the characteristic disease symptoms.

4. The pathogen should be re-isolated from these experimental animals and cultured again in the laboratory, after which it should still be the same as the original pathogen (Brock, 1979).

These postulates can be used in conjunction with the research approach recommended for each of the four categories that are designed to effectively direct efforts towards problems caused by biological agents in the marine environment. Table 6 is a presentation of examples from each of the four categories. A discussion of the research needs related to each category is presented below.

Table 6. Categorization of Biological Agents by Level of Knowledge

Category	Incidents					
1. Observable events for which we have no understanding of cause	Clam neoplasms, Coral bleaching events, Whale and dolphin beachings, Sea urchin mortalities					
	Biological Agents					
	Bacteria	Virus	Fungi	Protozoa	Toxic Plankton	Bioengineered and Introduced Species
2. Agents suspected to impact marine organisms, but evidence is lacking.	Coliform bacteria	Rotavirus Rabdovirus Retrovirus	None	*Paramoeba perniciosa*	None	*Pseudomonas putida*
3. Agents known to affect marine animals, *spp.* but knowledge of impact is incomplete	*Salmonella spp* *spp.*	Colicivirus Microbacteria	Saproleg- Herpes	*Hematadinium*	*Porocentrum* niaceae	None
4. Known to be an important agent in the marine environment, but unable to mitigate its impact	*Vibrio spp.* aerococcus	Influenza A Baculovirus	*Ichthyo-phonus spp.*	*Minchinia nelsoni, Dermocysti-dium marinus, Paramoeba perniciosa*	*Ptychodiscus brevis, Protogonvau-lax spp., Gambierdiscus toxicus*	*Minchina nelsoni*

Cause Unknown

In the case of events where the cause of disease or mass mortalities in marine organisms is unknown, research could be directed to fulfill Koch's postulates to identify the causative agent of the disease. Once the identity of the agent is determined, research could be directed at developing more complete knowledge of the impact of the agent on marine resources.

Biological Agents Suspected

As in the case of events where the cause is unknown, if a biological agent is suspected of causing an impact on marine resources but evidence linking disease or mortality to the agent is lacking, research directed at fulfilling Koch's postulates would be most useful. Once such a link is established, research should focus on gaining a better understanding of the impact of the biological agent on living marine resources.

Knowledge of Impact Incomplete

In those cases where a biological agent is known to affect marine organisms but knowledge concerning the impact is incomplete, research on determining the connection between the biological agent and natural events and human activities causing the outbreak, as well as on quantifying the extent of the impact on marine organisms would be most useful. This would include research on the following:

- o Persistence and transport mechanisms;
- o Host range and vectors/alternate hosts;
- o Host defense mechanisms and virulence of pathogen;
- o Role of environmental factors on pathogen interactions; and
- o Development of rapid diagnostic techniques.

Mitigation of Impacts

Once knowledge concerning the impact of a biological agent on living marine resources is adequate, research should be directed toward mitigating those impacts. This would include determination of control points and mechanisms of pathogenicity of these biological agents. In addition, efforts should include basic research into population genetics, population dynamics of host and pathogen, host range and response, the production of toxins or metabolites, and complex interactions with other pathogens, hosts, or chemical pollutants.

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GOAL 4: UNDERSTAND THE EFFECTS OF LOSING OR MODIFYING MARINE HABITATS AS A RESULT OF HUMAN ACTIVITIES

Marine and estuarine habitats are being lost at an alarming rate in many parts of the country. These losses are due to the direct and indirect impacts of human activities, as well as to natural phenomena. Declines in the quantity and quality of marine habitats is thought to reduce production of living marine resources and to diminish other important values of habitats. Continued shifts of human populations to coastal areas will increase pressures on marine habitats in the future. Therefore, understanding the effects of human activities on marine habitats is one of the six goals of the National Marine Pollution Program.

Goal Definition

Marine and estuarine habitats perform important functions for all living marine resources. Habitats are used by these species for spawning, rearing, feeding, migration, and shelter from predators. Populations of living marine resources are frequently limited by the quantity and quality of habitat. Numerous studies have demonstrated the possibility of an important relationship between yields of commercially valuable fisheries and acres of habitat available to the harvested species (Turner, 1977; Deegan and Day, 1984; Herke, 1971; Yakupzack et al., 1977; Knudson et al., 1977; Weinstein, 1979; Weinstein and Brooks, 1983; Mock, 1967). As habitats continue to be lost or damaged due to human activities, there is concern that a decrease in living marine resources will result.

Many marine and estuarine habitats, in particular vegetated wetlands (tidal marshes), perform other valuable functions to man and the environment. These functions include erosion and flood protection, water quality control, and waterfowl and wildlife utilization.

Marine and estuarine habitats may be organized into the following groups:

- o Emergent vegetated wetlands
  - marshes
  - mangroves
- o Submerged aquatic vegetation (SAV)
  - seagrasses
  - other submerged plant communities
- o Hard bottoms
  - coral reefs and rocky bottoms
  - rocky shores
- o Soft (unconsolidated) bottoms
  - mud flats
  - sand/shell beaches
  - subtidal soft bottoms
- o Shellfish beds
  - oyster reefs
  - clam beds
- o Water column

Although all of these habitat groups were considered in the development of this chapter, the text will focus primarily on emergent vegetated wetlands. This is due to the recognized ecological value of wetlands and the rapid rate of their deterioration and loss in many coastal areas. Alteration of the water column from the presence of marine debris is also considered important and warrants some discussion due to its adverse impacts on marine life and coastal communities.

The human activities that contribute the most direct impacts to habitat loss and modification are those causing physical alterations. These activities will be the focus of this section. The effects of chemical contamination on living marine resources and their habitats are considered in other sections of this Plan. Examples of human activities that cause direct physical alterations of marine and estuarine habitat include:

1. Drainage for crop production, timber production, and mosquito control;

2. Dredging and stream channelization for navigation channels, flood protection, coastal housing development, and reservoir maintenance;

3. Filling for dredged material and other solid waste disposal, roads and highways, and commercial, residential, and industrial development;

4. Construction of dikes, dams, levees, and seawalls for flood control, water supply, irrigation, and storm protection;

5. Mining of wetland soils for peat, coal, sand, gravel, phosphate, and other materials (Tiner, 1984);

6. Extraction of groundwater, oil, gas, and sulphur; and

7. Overboard garbage disposal, abandonment of fishing gear, oil rig and drilling platform operations, discharges municipal and industrial wastes, and public littering.

Physical alterations may cause habitat loss directly by removal or indirectly by modifying natural processes that significantly affect habitat. These natural processes include freshwater inflow, hydrology, sedimentation, and sea-level changes. In addition, marine debris is considered a physical alteration of the water column that poses a serious threat to the health and safety of marine animals. A discussion of the relationship between physical alterations and each of the processes is provided in the sections that follow.

Freshwater Inflow

Diversion of freshwater for agricultural, industrial, and domestic purposes can have a detrimental impact on estuarine habitat by upsetting the balance of fresh- and seawater flows. Of special concern is the relationship of freshwater flow to estuarine hydrography including sedimentation, nutrient dynamics, biotic distributions, primary productivity, food webs, and pollutant distribution (Thayer et al., 1985; NOAA, 1987b; Soniat and Boesch, In press).

Recruitment of many fish and shellfish species is closely linked to the hydrodynamics of estuaries and associated coastal waters, as are the composition and well-being of estuarine plant communities. Changes in freshwater flows affect the amount of sediment, nutrients, and organic carbon entering the estuary from terrestrial sources. This in turn can affect the composition and production of both plant and animal populations present in an estuary (Thayer et al., 1985).

Alterations in natural estuarine flow patterns and salinity regimes encourage salinization of brackish waters and/or rapid influxes of freshwater into upper estuaries. This in turn can affect various life history stages and routes of migration as well as feeding habits of certain invertebrate and fish species (Thayer et al., 1985; ASLO, In press). Increases in salinity, for example, may increase the number of high-salinity predators and diseases of oysters (Soniat and Boesch, In press).

Hydrology

Flood frequency and duration, water depth, and water velocity influence the types of vegetation, soils, and biota present in a marsh (Turner et al., 1984; Zedler and Beare, 1986). Although wetland plants are flood-adapted, they are also sensitive to changes in the hydrologic regime. Hydrologic changes having a major effect on habitat occur as a result of changes in freshwater inputs, direct man-made physical alterations to habitat (such as canal building), and relative changes in sea level.

The construction of canals and the associated deposit of dredged sediments in banks of the canals (disposal banks) has become a major influence on hydrology in wetlands. Turner and Cahoon (1987) attributed major changes occurring in south Louisiana wetlands to disposal bank creation, which results in changes in the hydrology of the adjacent marsh. Disposal banks cause increased flood duration and a decrease in the number of flooding and drying cycles due to the impediment of water flow through a marsh. The increased elevation of disposal banks can also result in a decrease in soil moisture and salinity, which allows invasion of the marsh by terrestrial plant species and elimination of marsh species. Additionally, disposal banks can increase waterlogging in an adjacent marsh, resulting in an increase in stress on the marsh, a decrease in its productivity, and eventual deterioration (Turner and Cahoon, 1987).

Hydrologic cycles also influence the nitrogen regime in wetland ecosystems by regulating the input of the nutrient into, and out of, the marsh (Turner et al., 1984). Nitrogen is often the primary limiting growth factor for rooted wetland macrophytes (Mendelssohn, 1979), and any changes in the availability of nitrogen could affect plant productivity (Turner et al., 1984).

Sedimentation

A continuous input of sediments to wetlands is necessary to counteract erosion, the effects of sea-level rise, and natural compaction of deposited sediments. Without sufficient input of new sediments, wetland areas would eventually be converted from one habitat type to another (high marsh to low marsh) and would eventually be completely submerged. Sedimentologic modifications are occurring in many wetland areas as a result of changes in freshwater input (e.g., upstream reservoirs), channel deepening, cutting of navigation canals, levee construction, and agricultural practices. With a decrease in the volume of freshwater flowing into a marsh is an accompanying decrease in the natural inputs of suspended sediments available for trapping by wetland vegetation and marsh accretion (Soniat and Boesch, In press). In addition, levees, channels, and river-control structures act to trap the flow of water and associated sediments and prevent over-bank flow of muds and fine sands during flood conditions (NAS, 1987). As a result, suspended sediments are either deposited onto the continental shelf and not into the marsh (Titus, 1986) or, in the case of river-control structures, trapped upstream. Without an influx of inorganic riverborne sediments, the marsh surface can only accrete vertically by biogenic production, which is often not adequate to keep pace with rising sea levels, and the marsh will eventually be submerged (NAS, 1987).

Increased sediment loads can have negative impacts on marine and estuarine habitats. Shoaling as a result of increased sediment loads can decrease the volume of an estuary and could lead to a decrease or change in habitat (ASLO, In press). Erosion of sediments from upland areas (e.g., agricultural lands and construction sites), discharges of dredged material, sloughing of channels, canals, and bayou banks, scouring of shallow bay bottoms, and the subsequent movement of displaced sediments can result in the eventual burial of areas downstream. This increased sedimentation could affect the fauna and flora in hard bottom and soft bottom areas. Oyster cultch materials could also be buried, thereby eliminating the bottom's ability to support oyster growth. Increased suspended sediments may also affect primary productivity due to its effect on the depth of the photic zone. Filter-feeding consumers may also be adversely affected by increased suspended-sediment loads (ASLO, In press).

Sea Level

Recent studies conducted by NAS and EPA suggest that the earth's temperature is expected to increase several degrees during the next century due to the greenhouse effect. The occurrence of such warming would cause a significant increase in the rate of sea-level rise around the world (Revelle 1983; Hoffman et al., 1983). Many wetlands have been able to keep pace with the relatively slow rise in sea level that has been occurring during the last few thousand years; however, if the sea level rises more rapidly than the marsh's ability to accrete new sediments, there will be a substantial loss of wetland area (Titus, 1986).

In addition to the increase in the volume of water in the world's oceans associated with accelerated global warming, subsidence in coastal areas is contributing to the relative rise in sea level along some coasts of the United States. Coastal subsidence along the Mississippi Delta is occurring at a rate that is five times as high as the average rate of global sea-level rise over the past century (Boesch et al., 1983). Large expanses of coastal marshes in Louisiana are being flooded permanently by the rising sea level. This is contributing to an estimated loss of over 40 square miles of coastal marshes in the region each year (Fruge, 1982). The causes of subsidence are 1) base downwarping (downward geologic displacement) from sedimentary loading, 2) compaction of sediments, and 3) tectonic activities. Compaction of sediments is a result of several factors, both natural and manmade. The anthropogenic causes include lowering of the water table through extraction of groundwater, petroleum, salt, or sulfur and reclamation practices that employ diking, construction of water-control structures, and draining of lands for agricultural or urban use (Craig et al., 1979). Effects of subsidence in some regions is more severe due to reductions in sediment input.

The relative rise in sea level, whether it results from global warming or regional subsidence, will have three major types of physical effects on habitat: shoreline retreat, increased flooding, and landward movement of salt water. Shorelines will retreat because the very low land will be inundated and other land along the shore will erode. Those coastal areas not lost to rising sea levels will experience an increase in flooding due to higher storm surges, the movement of larger waves farther inland, and increased runoff due to a decrease in upland areas' ability to drain as a result of a higher water table. The relative sea-level rises will cause salt water to move farther inland, intruding into the groundwater, rivers, and estuaries, and may alter the local availability of freshwater and alter ecosystems (Hoffman et al., 1983). A change in the sea level itself will result in changes in the patterns of sedimentation and marsh accretion, circulation patterns, biochemical cycles, and primary and secondary production which, in turn, affect living marine resources (ASLO, In press).

Persistent Marine Debris

An increasing awareness of the problems associated with marine debris, which includes metal items, glass, tar balls, and plastics, has occurred during the past decade. Marine debris comes from a number of sources including fishing vessels, oil rigs and drilling platforms, garbage dumped overboard from ships, plastic manufacturing industries, sewer systems combined with storm runoff, docks and marinas, and public littering. The best estimates, made over a decade ago, indicate the amount of debris generated worldwide by ocean sources was 6.4 million metric tons per year in the early 1970's (NAS, 1975). The world's merchant shipping fleet, the major contributor of debris, discharged an estimated 5.6 million metric tons of debris per year (NAS, 1975).

Of all types of marine debris, plastics have caused the greatest threat to marine life. Unfortunately, the same properties that make plastics more desirable than other materials, lightweight yet strong and durable, are also the properties that cause problems in the marine environment. Accordingly, this section will address plastic debris. Over 6 billion pounds of plastic resins were produced in the United States by 1960 (SPI, 1986). Plastic sales by weight in the United States in 1984 were estimated at 55,751 million pounds (SPI, 1988). More plastics were produced in 1985 than metal, glass, paper, and leather. The major uses of plastics include transportation, packaging, building and construction, electrical and electronic goods, furniture and furnishings, consumer and institutional supplies, industry, and machinery (CEE, 1987).

The majority of plastic materials entering the ocean is fishing gear, packaging materials, convenience items, and raw plastics (Pruter, 1987). Raw plastics, commonly called resin pellets, are the form in which raw or "virgin" plastic is produced and transported for later manufacture into plastic products. The major sources of resin pellets to the marine environment have been plastic manufacturing plants and transportation systems. The concentrations of plastic pellets in river sediments below manufacturing plant outfalls have been found to be as high as 800 pellets per cubic centimeter (CEE, 1987).

Whether plastic products and pellets float or sink, they are significant threats to marine mammals, sea birds, turtles, fish, and crustaceans (Laist, 1987). Because plastic products are very durable, they have a long life expectancy in the environment, which increases the possibility of an encounter with marine life. It has been estimated that nondegradable plastics can exist intact up to hundreds of years in seawater (ITFPMD, 1988).

The effects of plastics on marine animals occur by ingestion or entanglement. Animals that ingest plastic matter may suffer blocked digestive tracks, damaged stomach linings, or lessened feeding drives (Laist, 1987). Entangled animals may drown, require more energy to swim due to the increased drag, be less able to catch food or escape predators, and suffer serious lacerations and infections.

Current data suggests that entanglement may be a more serious problem than ingestion (Laist, 1987). Declining populations of northern fur seals on the Pribilof Islands of Alaska have been associated with mortality caused by entanglement from debris and plastic packing bands originating from the driftnet and trawl fisheries (Fowler, 1987). Approximately 0.4% of the subadult male Pribilof Island fur seal population is currently entangled in debris (Fowler, 1988).

The entanglement of sea birds in net fragments, monofilament fishing line, and six-pack rings has also been documented (Schrey and Vaulk, 1987; CEE, 1987). Sea turtles are commonly entangled in monofilament fishing line, rope, trawl net, gill nets, and plastic sheets or bags (CEE, 1987). Significant mortality rates of endangered green turtles off Costa Rica have been linked to the ingestion of banana bags (Heneman and CEE, 1987).

Ghost fishing, the ability of derelict nets and traps to continue catching finfish and shellfish indefinitely, is a major concern of the marine debris problem. In one isolated case, 99 dead sea birds and over 200 dead salmon were found entangled in a mile-long section of derelict gillnet (DeGange and Newby, 1980).

Sea birds, turtles, and fish are the most common marine animals that ingest plastics. Sea birds are likely to ingest raw plastic pellets that resemble their normal prey: fish eggs or larvae (Laist, 1987; CEE, 1987; Fry et al., 1987). An accumulation of ingested pellets can cause reduced feeding drives that may lead to malnutrition (Ryan, 1988) or fatal internal injuries (CEE, 1987). Pellet ingestion has also been documented in bottom fish such as flounder and perch (CEE, 1987). Possibly mistaken for jellyfish or other prey, plastic bags and sheeting are commonly ingested by turtles (CEE, 1987; Laist, 1987) along with a variety of other debris (CEE, 1987; Carr, 1987) that can block their digestive system and cause death (CEE, 1987; Martin, 1987). Humpback, fin, and right whales have been observed trailing plastic fishing gear from their mouths at sea (Connor and O'Dell, 1988).

Persistent marine debris is also an aesthetic problem in coastal areas of the country. Beach wash-ups have not only cost thousands of dollars to clean up, they have also deterred tourists and caused substantial economic losses to the coastal industry (CEE, 1987). Financial losses have also been suffered by vessel owners due to fouled propellers and clogged cooling water intake systems.

Persistent marine debris causes problems worldwide; however, the persistent marine debris problem for most locations and species is not currently at the crisis stage according to information now available (ITFPMD, 1988). However, near-term implementation of programs and regulations to reduce the impacts of marine debris could readily prevent numerous and unnecessary mortalities of marine life that may otherwise reach crisis proportions in the future.

Federal Role

This section is a discussion of the Federal legislation, regulations, and programs that address the issue of habitat loss and modification. Additional discussions of Federal programs as related to specific information needs are presented under the management questions that follow this review of the Federal role. More detailed information on the Federal programs and projects that address the issue of habitat alterations can be found in the National Marine Pollution Program, Summary of Federal Programs and Projects (NOAA, 1987c).

Federal Legislation and Regulations

Section 404 of the Federal Water Pollution Control Act (Clean Water Act) provides the major avenue of Federal involvement in controlling the use of wetlands and other marine habitats by regulating discharges of dredged or fill material into the waters of the United

States. Under Section 404, persons seeking to conduct such activities must first obtain a permit from the local district office of the U.S. Army Corps of Engineers (COE). The Environmental Protection Agency (EPA), National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service (FWS) of the U.S. Department of the Interior, and state agencies review these permit applications and provide comments and recommendations on whether permits should be issued and under what conditions. The COE then evaluates the impacts of proposed development activities on wetlands and other marine habitats in light of its regulations and comments received from these agencies. If expected impacts are judged to be significant, the permit application can be denied, or the project can be modified to minimize impacts. If there are no practicable alternatives and the project is in the public interest, mitigation can be required to compensate for the damage caused by the permitted activity. The EPA has the authority under Section 404(c) to overrule the use of any disposal site included in a COE permit application if it determines that the expected discharge would have an unacceptable adverse impact on municipal water supplies, shellfish beds and fishery areas (including spawning and brooding areas), wildlife, or recreational areas (40 CFR Part 231).

Section 404 only regulates the discharge of dredged or fill materials. Projects involving excavation, drainage, clearing, and flooding of wetlands are not explicitly included. Section 10 of the Rivers and Harbors Act of 1899 requires permits from the COE for dredging and other activities that could obstruct the navigable waterways of the United States, defined as those waters below the mean high-tide level, including tidal wetlands. Section 10 has served to protect tidal wetlands from activities such as dredging that are not covered by Section 404.

The NMFS and the FWS have legislative responsibilities to manage fish and wildlife resources and their habitats. The two agencies have common interests in some marine resources and their habitats in coastal waters, estuarine areas, and waters occupied by anadromous fishes. The responsibilities of NOAA's NMFS include management of marine fish located primarily in the Exclusive Economic Zone; anadromous fish; conservation of certain species of marine mammals (whales, dolphins, seals, and sea lions); and protection of endangered or threatened marine species (including sea turtles when in the water). The responsibilities of the FWS include, but are not restricted to, management of migratory waterfowl, anadromous fish, endangered species, and resident freshwater fish, and protection of certain species of marine mammals (manatees, polar bears, sea otters, and walruses), and sea turtles when they come ashore.

The Fish and Wildlife Coordination Act (FWCA) and the National Environmental Policy Act (NEPA) are the major authorities under which NMFS and FWS conduct aquatic habitat conservation activities, although significant additional environmental legislation has been passed since 1970 that gives the two agencies further authority over marine habitats. The FWCA requires interagency consultation to assure that fish and wildlife resources are considered when determining the economic and social concerns of a proposed Federal or federally authorized project that controls, modifies, or develops the Nation's waters. The NMFS and FWS analyze a wide variety of projects under the FWCA, including COE dredge and fill permit applications for U.S. waterways, hydroelectric power project proposals, and other Federal water projects.

Additional FWS mandates related to habitat include Sections 401 and 402 of the Emergency Wetland Resources Act of 1986 (P.L. 99-645). Section 401 of the Act requires the Secretary of the Interior to produce detailed wetland maps for the contiguous United States by September 30, 1998, and for Alaska as soon as possible after that date. The Section also requires FWS to update its report on the status and trends of the Nation's wetlands by 1990 and every 10 years thereafter. Section 402 requires the Secretary of the Interior to submit reports to Congress describing the status, condition, and trends of wetlands in the United States. These reports are to contain an analysis of the factors responsible for wetlands destruction, degradation, protection, and enhancement and an analysis of the direct and indirect effects of Federal programs on wetlands.

Additional NOAA mandates related to habitat include the Magnuson Fishery Conservation and Management Act (P.L. 94-265; Magnuson Act), which requires NMFS to conserve and manage U.S. living marine resources, principally within the U.S. Exclusive Economic Zone, although there is concern about management throughout the range of the resources. The Magnuson Act provides for the consideration of living marine resource habitat in the development of fishery management plans.

The International Convention on the Prevention of Pollution by Dumping of Wastes and Other Matter, London, 1972, also known as the London Dumping Convention (LDC), prohibits the deliberate disposal into the sea of "persistent plastics and other persistent synthetic materials," which include netting and ropes. The definition of dumping, however, excludes "the disposal of synthetic debris at sea during the course of normal vessel operations."

Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) was unanimously ratified by the U.S. Senate on November 5, 1987 and goes into effect on December 31, 1988. The U.S. Coast Guard is currently drafting the regulations for implementing the pollution prevention requirements of Annex V. Annex V prohibits ships representing the member nations from the "disposal into the sea of all plastics, including but not limited to synthetic ropes, synthetic fishing nets and plastic garbage bags" with limited exceptions. Under Annex V, synthetic debris, generated as a result of normal vessel operations, cannot be discarded at sea as was previously allowed under the LDC.

The Marine Plastic Pollution Research and Control Act of 1987 (P.L. 100-220) amends the 1980 Act to Prevent Pollution from Ships (APPS, P.L. 96-478) and provides for the implementation of Annex V of MARPOL 73/78. It also calls for a research effort to identify and reduce the effects of plastic debris in the marine environment and to conduct a public outreach/education program on plastics pollution. Title IV, the Driftnet Impact Monitoring, Assessment, and Control Act of 1987 (P.L. 100-220) has several provisions, one of which requires the Department of Commerce to investigate the feasibility of a driftnet marking, registry, and identification system; the use of alternative driftnet materials; a driftnet bounty system; and a driftnet vessel tracking system.

Federal Programs

Several Federal agencies conduct research, development, and monitoring activities related to the effects of human destruction and modification of marine habitats. The agencies with major roles in habitat research include COE, USDA, NOAA, and FWS.

Habitat-related research and monitoring is conducted by COE at the Waterways Experiment Station (WES) in Vicksburg, Mississippi and at its division laboratories. Most of the COE's research activities address the effects of dredged material disposal in aquatic systems. Such activities include assessing various disposal techniques through monitoring of disposal sites, development of alternative disposal methods, and characterization of biological, physical, and chemical characteristics of historical and future disposal sites. WES studies the effects on living marine resources and their habitat of coastal engineering projects, such as beach nourishment, channel deepening, and jetty construction. In addition, WES is developing techniques for using dredged material for habitat creation (oyster reefs, sea grass beds, and other wetland habitats) and for abating shoreline erosion using marsh plants and seagrasses to stabilize sediments and reduce wave energy. WES also conducts research to identify and delineate wetlands and to assess wetland functions and values.

NOAA's research and monitoring activities are conducted primarily by the National Marine Fisheries Service (NMFS), the Sea Grant Program of the Office of Oceanic and Atmospheric Research (OAR), and the Strategic Assessments Branch of the National Ocean Service (NOS). Other NOAA offices and programs that address habitat issues include the Deep Seabed Mining Environmental Research Program and the National Marine Sanctuaries Program of NOS, and OAR's Environmental Research Laboratories. NOAA conducts studies on wetland functions, such as the habitat utilization and requirements of commercial, recreational, and endangered species and the relationship between plant primary productivity and living marine resource production. The agency conducts research and monitoring to determine the direct and long-term effects of various environmental alterations such as freshwater diversions, dredging, and impoundments, on the spatial distribution and quality of coastal wetlands and their resulting impacts on living marine resources. Both NMFS and OAR are developing and evaluating various techniques for creating and restoring wetland habitats. NOAA is also compiling a database of the areal extent and distribution of coastal wetlands in the United States.

The USDA's habitat research is concerned with the effects of agricultural practices on estuarine habitats. Studies include the effects of landscape changes, channelization, and drainage, which result in potential increased sedimentation (through erosion of soils), subsidence, and other physical alterations in habitat. The agency also investigates the relationship between fish abundance, distribution, reproduction, health, and productivity and the habitat changes resulting from natural and human-induced events.

The FWS conducts research on the structure and functions of wetlands with regard to their relationship to waterfowl, fish, and wildlife populations. The agency also evaluates changes in wetland acreage, structure, and function caused by natural processes and human activities and develops and evaluates methods for mitigating the loss or alteration of wetlands. Under the National Wetlands Inventory Program, FWS has developed, and is currently updating, a wetland database (in map form) on the characteristics and extent of the nation's wetlands and deepwater habitats. Based on this database, FWS periodically reports on the status and trends of the nation's wetlands.

Other Federal agencies conducting habitat-related studies include the U.S. Geological Survey (USGS) and the Minerals Management Service (MMS) of the U.S. Department of the Interior, and the EPA. The USGS is conducting research designed to understand the geological, oceanographic, and other causes of coastal erosion by means of surveys and other measurements, and is providing information to various Federal and state agencies about the nature, extent, and rate of coastal retreat and land loss. The MMS funds efforts to determine the impacts of Outer Continental Shelf (OCS) oil and gas development on coastal and wetland habitats. The EPA's Environmental Research Laboratory in Corvallis, Oregon is currently conducting research on wetland mitigation, cumulative impacts, and water quality functions of wetlands.

NOAA's Marine Entanglement Research Program (MERP) within NMFS is involved in a variety of efforts to address the problems of persistent marine debris. MERP sponsors research on the effects of pellets, fishing gear, packing straps, and six-pack rings on marine life; funds reviews of technology and processes pertinent to plastic waste management, such as degradable plastics and the Marine Refuse Disposal Project in Newport, Oregon; develops methods to reduce the ocean disposal of ship-generated garbage; and promotes education/public awareness through workshops, conferences, published materials, and educational contractors.

The MMS, National Park Service (NPS), and the FWS of the U.S. Department of Interior conduct activities concerning persistent marine debris. Educating Gulf of Mexico users about the problems of marine debris and strictly controlling persistent solid waste disposal from Federal OCS oil and gas facilities are MMS's responsibilities. The NPS aids in the source identification of marine debris washed up on beaches and conducts education/awareness activities. The FWS researches the effects of plastic debris on wildlife and educates fisherman of the threat posed to marine life by discarded plastics (ITFPMD, 1988).

Other Federal agencies involved in marine debris include the U.S. Navy, which is currently researching and developing methods for the processing and storage of ship-generated waste; the EPA, which funds various marine debris projects such as identifying the sources and types of floatable matter on New Jersey beaches and sampling the outfall waste stream of combined sewer overflow systems to determine their contribution to floatables in the marine environment; and the Marine Mammal Commission, which is involved in education/awareness programs including annual meetings, workshops, and beach clean-up efforts (ITFPMD, 1988).

Management Questions And Information Needs

An understanding of the effects of human destruction and modification of marine habitats is needed to support effective management of these habitats and dependent living marine resources. Listed below are five management questions that have been developed to identify the information that environmental managers and decision makers are likely to need. These management questions are modified versions of those presented in the 1985 Federal Plan (NOAA, 1985a). During a recent workshop sponsored by the National Ocean Pollution Program Office (NOPPO), the management questions presented in the 1985 Plan were reviewed and recommendations for their revisions were made (NOAA, 1988). Following the workshop and further review by NOPPO and experts in the field of marine habitats, the management questions presented below were developed.

Management Question 1: What is the present status of marine habitat quality and quantity and how is the status changing?

Management Question 2: What are the causes, both natural and anthropogenic, of changes in the status of marine habitat quality and quantity?

Management Question 3: What are the short-term effects, direct and indirect, of habitat modification caused by human activities?

Management Question 4: What are the long-term and cumulative effects of habitat modifications?

Management Question 5: How effective are restoration and mitigation?

This section will evaluate how well we can answer these questions by using existing information. For each management question, the discussion will identify pertinent Federal programs, evaluate the adequacy of existing information for addressing the information needs, and present recommendations on the most important research, development, and monitoring opportunities for improving our understanding in each area.

Status Of Habitat Quantity And Quality

Management Question 1: What is the present status of marine habitat quality and quantity and how is the status changing?

Information Needs

1a. What are the existing acreages of habitats? How are they changing regionally and nationally?

1b. What are the natural functions, processes, and values of marine habitats?

1c. What are the habitat requirements of valued living marine resources?

Resource managers must have some understanding of the functions of habitat as well as the rates of habitat loss and change to manage living marine resources effectively by predicting the immediate and long-term effects of human activities on habitat (NOAA, 1987a). For most parts of the country, we have not quantified the functional value of estuarine habitats, the quality of the habitats, or their areal extent and rate of loss well enough to measure changes in their status. To minimize the impacts of habitat alterations, we must first understand the role and value of habitat types, inventory the destruction of habitats, and monitor habitat changes (NOAA, 1987a).

1a. What are the existing acreages of habitats? How are they changing regionally and nationally?

In 1986, Congress enacted the Emergency Wetland Resources Act in response to the need for effective management of wetland resources. This Act requires the Secretary of the Interior to produce detailed wetland maps for the contiguous United States by September 30, 1998, and for Alaska as soon as possible after that date. The Act also requires FWS to update its report on the status and trends of the Nation's wetlands by 1990 and every 10 years thereafter. The mapping of coastal wetlands has been an ongoing effort in the National Wetlands Inventory (NWI) program at FWS. About 93% of the wetlands in the coastal zone of the lower 48 states has been mapped. Other habitat types including submerged aquatic vegetation, rocky shores, reefs, and intertidal soft bottoms are also depicted in NWI maps although they are not covered as completely as the wetlands. The FWS published a report on habitat loss in the conterminous United States between the mid-1950's and mid-1970's (Tiner, 1984) and another report that documented habitat loss specifically in five Mid-Atlantic states (Tiner, 1987).

Although FWS has completed maps for the majority of the coastal wetlands in the lower 48 states, some of these maps (and the wetland loss rates derived from them) are 10 years old. Many regions of the country are undergoing rapid change (e.g., coastal Texas, the

Florida Bay marshes of the Everglades, and the bay margin marshes of the Mississippi River Delta), and these regions should be inventoried and mapped as frequently as needed to more accurately assess wetland status and trends.

NOAA's National Ocean Service, Strategic Assessments Branch (SAB) is preparing estimates of the areal extent and distribution of coastal habitat types in the conterminous United States (excluding the Great Lakes). The SAB is applying a systematic grid sampling procedure to existing NWI habitat maps to identify 15 different habitat types using a 45-acre grid cell size (Alexander and Field, 1986; Alexander et al., 1986). To date, over 2,550 of the 4,000 NWI maps available in coastal areas of the United States have been grid sampled. Grid sampling is expected to be completed by the end of 1988.

There have been efforts by some states and the FWS to develop high-resolution automated databases of habitat types through a process of digitizing NWI maps at a resolution of approximately one acre. The utility of high-resolution and geographically referenced databases for resource managers has been evaluated by FWS (Dahl, 1987). Digitizing NWI maps would make updating information on the status and trends of habitat types easier and more accurate; however, the progress towards digitizing all coastal wetland maps has been hampered by the time-consuming and costly nature of the process involved.

In addition to wetlands, attempts are being made to inventory other marine and estuarine habitat types. For example, in 1984, EPA's Chesapeake Bay Program began to coordinate a multiagency effort to record and map submerged aquatic vegetation in the bay. The program was jointly funded by the Maryland Department of Natural Resources, the Virginia Council on the Environment, the EPA, FWS, and COE (CBP, 1987). In addition, NOAA and FDA, with assistance from EPA and FWS, have compiled an inventory of the status of shellfish-growing waters in the lower 48 states (NOAA and FDA, 1985). The National Shellfish Register categorizes all shellfish-growing waters into one of five classifications: approved, conditionally approved, prohibited, restricted, and nonproductive. The Register also provides data on estimated acreage of classified shellfish waters by state.

Mapping and inventorying of habitats in those parts of the country undergoing rapid change should be conducted as frequently as needed. Also, costs and benefits of developing high-resolution, digitized wetland databases should be evaluated. In addition to wetlands, more complete and detailed inventories of other marine and estuarine habitat types known to be important for the production of living marine resources would be useful. These habitat types include shellfish beds, submerged aquatic vegetation, endangered species' habitats, and coral reefs (NOAA, 1988).

1b. What are the natural functions, processes, and values of marine habitats?

Several wetland functions, including flood and erosion protection, fisheries habitat, and water quality control, have been identified. Physical alterations of wetlands can affect their ability to perform these natural functions by reducing the areal extent or quality of these habitats.

Methods have been developed by various Federal agencies (NOAA, COE, FWS, DOT) to assess the relative functional values of wetlands. Of these methods, COE's Wetland Evaluation Technique (WET) (Adamus et al., 1987), a revision of a method first developed for the Federal Highway Administration of the Department of Transportation (Adamus and Stockwell, 1983), is the most widely accepted. All of these methods, however, are limited by the level of understanding of the actual processes taking place in habitats, which vary with habitat type, region of the country, and physical, chemical, and biological conditions. Therefore, better knowledge of these processes is required to improve our capabilities for evaluating change in the functional value of wetlands.

A better understanding of estuarine dynamics and its importance to selected habitat functions would improve the Nation's ability to manage critical habitats and other valued marine resources. Research could be conducted to understand the combination of conditions that produce unique hydrodynamic and biological environments (NOAA, 1987a). Studies in estuaries of different sizes, bathymetrics, climate regimes, and types that consider all major physical and chemical processes as they relate to circulation, mixing, and internal density changes would be useful. There is a need to understand the relative importance of each process, judge which are the most influential for various habitat types, and determine the water quality and biological response.

<u>1c. What are the habitat requirements of valued living marine resources?</u>

Of all the functions of habitat, its value in supporting commercial and recreational fisheries has received the most attention. Researchers have determined which habitat types appear to be important to living marine resources, but the specifics of how these habitats are used or which aspects of habitats make them valuable for the production of living marine resources are poorly known. For example, high levels of estuarine secondary production appear to be associated with high levels of estuarine plant productivity; however, the relationship between primary and secondary productivity is not well understood (NOAA, 1987b).

Studies to assess the habitat requirements of, and use by, selected fisheries species have been or are currently being conducted or funded by NOAA through the OAR and NMFS, as well as through the FWS and COE. The OAR has funded studies to determine the habitat requirements of commercial and recreational species in various regions of the country and to evaluate the functions of habitat in terms of such factors as critical refuge, food resources, and reproduction of economically and ecologically important fishes and macroinvertebrates. The NMFS conducts life history and habitat investigations of important commercial and recreational finfish and shellfish as part of its management of fishery resources in the U.S. Exclusive Economic Zone. The FWS and COE have jointly produced a series of species profiles, which describe the life histories and environmental requirements of many commercial and recreational species along the coasts of the United States. Habitat requirements are known for many economically important species such as the Gulf menhaden, shrimp, and blue fish; however, there are considerable gaps in the technical information for most other species.

Knowledge of comparative values of regional habitats to fishery production is important in managing the resources. Methods to quantitatively evaluate the importance of one habitat as opposed to another would be useful. This would require determining the factors that limit the overall success and productivity of the populations of concern and developing predictors of the relative importance of habitats to these populations.

Causes of Habitat Loss and Modification

Management Question 2: What are the causes, both natural and anthropogenic, of changes in the status of marine habitat quality and quantity?

Information Needs

2a. What are the human activities (types and number of projects, nationally and regionally) that cause direct physical alterations and changes in freshwater input, hydrology, sedimentologic processes, and relative sea level?

2b. What are the natural processes and anthropogenic factors that control accretion, erosion, and sedimentation rates?

2c. What will happen to coastal wetlands as a result of sea-level rise?

2a. What are the human activities (types and number of projects, nationally and regionally) that cause direct physical alterations and changes in freshwater input, hydrology, sedimentologic processes, and relative sea level?

To understand the magnitude of potential short- and long-term as well as cumulative impacts of human activities on habitat, we need to identify and quantify those human activities that have the most serious impacts on habitats. Major attempts by the Federal Government to quantify the loss or modification of habitat and to address the causes of changes resulting from human activities include studies conducted or funded by NOAA (NMFS, National Ocean Service, and OAR), and the Department of the Interior (MMS and FWS). The NMFS Southeast Region and Center are developing a system to document their efforts in conserving habitat in COE's permitting program. The system uses information collected during the COE permitting process, including data on project type, purpose, and location; habitat type affected; area proposed to be affected; area NMFS recommended to be conserved or did not object to its being altered; and NMFS' recommended mitigation or compensation (Lindall and Thayer, 1982). The Strategic Assessments Branch of NOAA's National Ocean Service has compiled shoreline and dredging characteristics for 92 estuaries identified in its National Estuarine Inventory (Orlando et al., 1987). The Sea Grant Program is supporting studies to quantify the parameters that influence landscape structure and function and to inventory and classify impoundments in coastal Louisiana.

The MMS has supported a study conducted by Louisiana State University to determine how much and in what ways OCS oil and gas development has contributed to wetland loss in coastal Louisiana and parts of Texas and Mississippi (Turner and Cahoon, 1987). Finally, the FWS has proposed a study for FY 1989 to analyze the effectiveness of the 404 program in retarding coastal wetland loss by comparing the pre- and post-404 implementation status of wetlands in several estuaries along the coasts of the United States (FWS, 1987). This effort will utilize current digital databases and wetlands maps prepared by FWS and others such as states and NOAA, and historical mapping where available. Additional mapping (historical and recent) and digitizing will be completed to provide status and trends data.

An inventory system for federally permitted activities that affect marine and estuarine habitats would help us to document the human activities that are causing loss and modification of coastal habitats in the United States. This system could record nationwide coastal habitat *changes caused by Federal projects, federally permitted projects, and other authorizations. The accounting system of habitat loss and modification would also consider indirect changes in habitat attributable to alterations in habitat processes caused by human activities, such as freshwater diversions in upland areas that impact estuarine habitats.*

<u>2b. What are the natural processes and anthropogenic factors that control accretion, erosion, and sedimentation rates</u>?

Geologic processes are of major importance in shaping habitats. Identifying the factors, both natural and manmade, that contribute to the accretion, erosion, and sedimentation rates of coastal habitats is of particular concern. Due to the present worldwide rise in sea level coupled with subsidence which is occurring in many coastal areas, continuous deposition of sediments in coastal wetlands is necessary to allow accretion and to prevent permanent flooding and erosion of coastal areas. As a result of man's activities, sediments are not being introduced in sufficient quantity to keep pace with relative sea-level rise, and some coastal margins are rapidly being eroded. To help prevent further loss of land, identification and quantification of those processes that affect accretion, erosion, and sedimentation rates are needed as well as an evaluation of the ways in which future activities may be modified to reduce impacts.

Several Federal agencies, including DOI (FWS, MMS, and USGS), COE, and USDA, are currently addressing, or have in the past addressed, various aspects of accretion, erosion, and sedimentation rates in coastal habitats. Within the Department of the Interior, FWS and MMS have sponsored research addressing the causes and consequences of coastal erosion and subsidence in coastal Louisiana. The USGS has conducted research to understand the geological, oceanographic, and other causes of coastal erosion and to determine the nature, extent, and rate of coastal retreat and land loss. The USDA and cooperating state agricultural experiment stations are conducting research to evaluate the effects of landscape drainage and channel modification on ambient concentrations of sediments and subsidence and the influence of sediments being deposited in coastal wetlands and other target areas. For several years, COE has been investigating causes of beach erosion, methods to control erosion through shoreline stabilization, and the physical processes contributing to erosion.

Given the current level of knowledge of geologic processes affecting habitat, the development and testing of conceptual models would help predict changes in accretion, erosion, and sedimentation that occur as a result of human activities and natural processes. These models would assist in identifying information gaps. Also, they would allow for comparison of geologic processes in habitats of different parts of the country (e.g., Northeast vs. Chesapeake Bay vs. the Gulf of Mexico) to determine why some habitats are eroding.

<u>2c. What will happen to coastal wetlands as a result of sea-level rise</u>?

Eustatic sea-level rise is a major process affecting habitat that is more predictable than changes in the other processes. Studies conducted by the National Academy of Sciences (Revelle, 1983) and EPA (Hoffman et al., 1983) indicate that the current rise in sea level will continue throughout the next century. Hoffman et al. (1983) estimate that sea level could rise by as much as 3 to 4 1/2 feet by the year 2075. This steady rise in sea level, together with subsidence that is occurring along some coastal margins (particularly in the Mississippi Delta), is causing land loss of intertidal wetlands at a significant rate.

Several EPA studies have predicted future sea-level rise and the effects it will have on coastal areas (Titus, 1986 and In press; Hoffman et al., 1983; Kana et al., 1986). In addition to the EPA's efforts, some academic research has been conducted with Federal funding from NOAA (OAR), NSF, DOI, (FWS and USGS), and COE. For example, Stevenson et al. (1986) discuss the ability of marshes to keep pace with sea level through accretion.

Models to predict impacts of sea-level rise on wetlands such as that developed by the EPA for South Carolina (Kana et al., 1986) would help to evaluate the impact of sea-level rise for selected coastal wetland regions that are expected to be most severely affected by sea-level rise. These models would be based on more refined assumptions used to predict future sea-level rise and the resulting impacts on wetland loss. The expansion of the tidal gauge analyses proposed in NOAA's National Climate Change initiative is one way to provide data to refine model assumptions.

Short-Term Effects

Management Question 3: What are the short-term effects, direct and indirect, of habitat modification caused by human activities?

Information Need

3a. What are the short-term effects, direct and indirect, of anthropogenic physical alterations on habitat quality and quantity?

3b. What are the short-term effects of debris in the marine environment?

3a. What are the short-term effects, direct and indirect, of anthropogenic physical alterations on habitat quality and quantity?

Environmental assessment specialists and resource managers must evaluate the impacts of human activities that may affect habitat. However, quantitative and qualitative information is generally lacking on the specific environmental effects of various activities themselves or the effectiveness of various mitigation options in avoiding or reversing these effects (NOAA, 1985b). When an understanding of habitat functions and characteristics that are altered as a result of man's activities is achieved, better prediction of the effects of habitat loss will be possible.

The problem of determining the short-term direct and indirect effects of human activities on habitat has been addressed by several Federal agencies under their specific legislative mandates. These agencies include USDA, NOAA (NMFS, OAR, and the National Ocean Service), COE, DOI (MMS and FWS), and EPA. Much has been learned about how human activities result in the quantitative loss or modification of habitat, but additional research would help to determine how such losses or modifications result in changes in the quality and function of various habitat types. However, without an understanding of the natural processes and function of habitats, a sufficient understanding of the effects that human activities will have on habitat quality cannot be attained.

Case studies could be conducted to improve our understanding of the indirect effects of physical alterations on habitat quality and function. These studies would involve assessments of changes in the processes that affect habitat (hydrology, sedimentation, relative sea-level changes, and freshwater inflow).

<u>3b. What are the short-term effects of debris in the marine environment?</u>

The most significant short-term effects of debris in the marine environment concern fish and wildlife, coastal communities, and vessels. Unfortunately, adequate information is not presently available to accurately assess the effects in any of these areas. According to the Interagency Task Force on Persistent Marine Debris (ITFPMD, 1988), the existing research information concerning the effects of persistent marine debris on most species of wildlife is inconclusive. Exceptions include the northern fur seal and the Hawaiian monk seal which are frequently entangled (Fowler, 1988). Significantly more information is available on the effects of certain types of persistent marine debris, including nets, six-pack rings, and plastic bags, on individual marine animals such as fish, birds, turtles, and mammals (Fry et al., 1987; Ryan, 1988) than is available on the effects of persistent debris on other populations of marine species. The information available on the economic effects of plastic debris from ocean sources on coastal communities tends to represent individual cases; regional or national cost evaluations are not available (ITFPMD, 1988). The disablement effect of marine debris on vessels, such as the fouling of propellers and the clogging of cooling water intake systems, is a recognized problem; however, comprehensive data is lacking on the frequency of these occurrences (CEE, 1987).

Under the Marine Protection, Research, and Sanctuaries Act, the Marine Mammal Protection Act, the Endangered Species Act, and the Magnuson Fishery Conservation and Management Act, NOAA is responsible for protecting, conserving, and managing marine species and their habitat (ITFPMD, 1988). The Federal agencies that play a large role in sponsoring or conducting research on the effects of persistent marine debris are NOAA (under the Marine Entanglement Research Program of NMFS) and FWS. Additional information concerning the research performed under NOAA and FWS is provided in the Federal Programs section of this chapter.

In an effort to help reduce the plastic debris problem, the plastics industry has developed degradable, or controlled lifetime, plastics, such as photodegradable six-pack rings, and the Stevens Institute of Technology's Polymer Processing Institute recently received a grant to develop materials for fish traps and pots that will degrade in seawater (ITFPMD, 1988). Degradable plastics are also being considered for tampon applicators, styrofoam containers, and balloons (ITFPMD, 1988). The concept of applying the technology of controlled lifetime plastics to fishing gear is also being discussed; however, there is concern over potentially dangerous premature failure. The existence of such technology may be useful for fishing gear items with limited useful lifetimes (ITFPMD, 1988; Andrady, 1988).

Degradable plastic products cannot be reused, recycled, or have their heat content recovered. Also, the possibility exists that making disposable items degradable will encourage their improper disposal into the environment.

Research and monitoring efforts to identify and quantify the effects of marine debris on populations of fish and wildlife (particularly endangered, threatened, or depleted species), coastal communities, and vessels would improve our understanding in this area (ITFPMD, 1988).

In addition, many scientists and organizations are concerned with the environmental and waste management impacts posed by degradable plastics. There is a need to research the environmental effects of the byproducts of degradable plastics (ITFPMD, 1988). If these effects are determined to be environmentally acceptable, the technologies should be further developed and uses of degradable plastics for items such as fishing gear should be applied.

Long-Term and Cumulative Effects

Management Question 4: What are the long-term and cumulative effects of habitat modification?

Information Needs

4a. What are the long-term effects of individual projects resulting in habitat modification or loss?

4b. What are the cumulative effects of several projects separated in either time or location, together with natural changes, that result in modification or loss of estuarine or marine habitat?

4c. What are the long-term effects of persistent debris in the marine environment?

The inability of researchers to predict the long-term and cumulative impacts of habitat alterations makes habitat management difficult, especially when there are substantial short-term economic benefits associated with the development of these areas. Although a single coastal development project that results in modification or loss of marine habitat may not have serious immediate environmental repercussions beyond the point of initial impact, many such projects in succession over time and over a broad geographic area may have far-reaching ecological consequences (NOAA, 1988). Without reasonably accurate information on long-term and cumulative impacts of human activities on marine and estuarine habitats, good decisions on permitting, mitigation, or management of fisheries and wildlife will be difficult.

4a. What are the long-term effects of individual projects resulting in habitat modification or loss?

A number of projects have been initiated by COE, NOAA (NMFS and Sea Grant), and FWS to address the long-term impacts of individual projects. These efforts should be continued with more work on monitoring previous project sites to assess impacts. Environmental impact statements (EIS) include estimates of impacts to habitat that are expected to occur as a result of specific COE-permitted activities. The EISs written several years ago should be reviewed and studies should be conducted to determine if the projected impacts actually occurred and if mitigations used were successful. Additionally, selected ongoing projects causing physical alterations should be monitored to assess long-term impacts.

<u>4b. What are the cumulative effects of several projects separated in either time or location, together with natural changes, that result in modification or loss of estuarine or marine habitat?</u>

Prior to 1984, the Federal Government had not conducted research specifically addressing the cumulative effects of modifications on living marine resources and their habitats, and relatively few studies have directly addressed the issue since that time. An example of the current research being conducted on cumulative impacts is an EPA-funded study by Louisiana State University. The LSU study, designed to develop a regional approach to cumulative impact assessment, is specifically concerned with bottomland hardwood forests in the lower Mississippi Valley (Gosselink et al., In press). This study investigates the minimum area needed to support living resources and addresses changes in habitat distribution, species composition change, and the effects of habitat or range fragmentation.

Research on cumulative effects of habitat alterations, including regional or watershed case studies of historical projects causing physical alterations, would improve our understanding of habitat loss and modification. Additionally, a framework for identifying the limits of acceptable habitat quantity and quality should be developed for each watershed.

<u>4c. What are the long-term effects of persistent debris in the marine environment?</u>

Assessment of the long-term effects of marine debris is very difficult, if not impossible, at this time for several reasons: the severity of the problems associated with persistent marine debris have only come to light during the past decade; the changes in the environment which will occur following the commencement of MARPOL 73/78 Annex V cannot be predicted; and applicable technologies that may reduce the overall problem are only now being developed. The implementation of Annex V (which becomes effective on December 31, 1988, one year after its ratification) should substantially reduce the amount of persistent marine debris discharged into the world's oceans and must be considered as a factor in the long-term analysis along with the potential widespread future application of plastics re-use, recycling, heat recovery, and the use of controlled lifetime plastic products. Annex V and these improved shore-based waste management technologies may reduce the persistent marine debris problem sufficiently to eliminate severe long-term effects such as the extinction of endangered species or continuous economic losses to coastal communities.

Research and monitoring of persistent marine debris should continue despite the commencement of MARPOL Annex V and the use of environmentally acceptable degradable plastics. Studies should be used to evaluate the effectiveness of these mitigation measures in protecting living marine resources, reducing vessel disablement, and lessening the economic losses to coastal communities.

Effectiveness of Restoration and Mitigation Efforts

Management Question 5: How effective are restoration and mitigation?

Information Needs

5a. What has been the success of past mitigation, restoration, and creation projects and other management techniques?

5b. What are the most effective methods and approaches for mitigation, restoration, creation, and other management techniques? How can they be improved?

Although Federal agencies often require mitigation or restoration as part of their permitting programs, it is not known whether the new or restored habitat, which was provided to compensate for the lost habitat, actually replaces the functional values of the lost habitat (NOAA, 1987a). Many researchers believe that most current and historic efforts at mitigation of coastal wetlands or other marine habitat loss have not been successful, and some have even resulted in additional environmental damage (NOAA, 1988). Therefore, knowledge concerning the effectiveness of mitigation and restoration is critical for the effective management of habitats through the permit-mitigation processes (NOAA, 1987a).

Past efforts to evaluate mitigation/restoration techniques have been conducted by COE, FWS, EPA, and NOAA (NMFS and OAR). These efforts have included studies to determine methods for restoring seagrasses, emergent wetlands, beach grasses, and other vegetative habitat types. They have attempted to evaluate the degree to which restored habitats function as compared with natural habitats and to identify the necessary construction specifications, factors most critical to the success of projects, and required monitoring procedures for evaluating mitigation/restoration projects. In addition to these efforts, a new study is being funded by the MMS Gulf of Mexico Region Office to investigate ways to reduce wetland loss, better manage wetlands, and to enhance existing wetlands.

To evaluate the success of various mitigation techniques in duplicating the natural functions of habitat will require additional study. For many habitats, it is possible to create a habitat in an engineering sense. For example, adequate information is already available to recreate Spartina alterniflora marshes and mangroves, and good progress is being made toward understanding how to create seagrass beds. What is as yet unknown, however, is how to measure the quality of restored habitat. Research could be helpful in determining the relative value of restored habitats, including sediment development, plant cover, microbial and detrital development, faunal utilization, and trophic linkages.

Conclusions and Recommendations

Marine and estuarine habitats are some of our most valuable natural resources. These habitats are used by living marine resources for food, spawning, rearing, protection from predators, and other life history requirements. Habitats provide other valuable functions to humans, including erosion and flood protection, water quality control, and wildlife and waterfowl utilization. Rapid coastal development is threatening our valuable marine and estuarine habitats. Although considerable research has been conducted in recent years to understand the value of habitats and the effects of destroying or modifying them, these issues still have not been adequately addressed.

The following conclusions concerning our knowledge of human impacts on marine and estuarine habitats are made based on the discussion of management questions and information needs presented in the previous section. These conclusions focus on our knowledge of physical alterations of habitat; the effects of chemical contamination on living marine resources and their habitats are discussed in other sections of this Plan.

- o The FWS wetland maps and estimation of wetland loss rates derived from these maps are as much as 10 years out of date and do not provide timely information on the status and trends of habitats in areas of most rapid change.

- o Although for the most part we know which causes, both natural and anthropogenic, result in habitat loss and modifications, we have not adequately quantified the human activities that are affecting wetlands, nor, in most cases, are we able to accurately predict how natural events or human activities will impact habitats.

- o Researchers do not have an adequate understanding of estuarine processes and their importance to habitat functions.

- o Without an adequate understanding of the natural processes and functions of habitats, we cannot accurately determine the effects that human activities will have on habitat quantity and quality, nor can we determine how well mitigation efforts actually replace the functional values of lost habitat.

- o A key issue for future habitat research will be to understand the cumulative effects of numerous projects over time and space on the quantity and quality of marine and estuarine habitats and the ecosystem.

- o Adequate information is not available to assess the effects of persistent marine debris on populations of living marine resources.

Based on these conclusions, the following recommendations are made to improve our understanding of the effects of loss and modifications of marine habitats as a result of human activities.

Status of Habitat Quantity

The following work is needed to improve inventories of habitat types and to document changes in the status of these habitats.

<u>Update NWI Maps</u>. Maps in rapidly changing coastal areas should be updated as frequently as needed.

<u>Automated Databases</u>. Several coastal states have digitized NWI maps using high resolution, geo-referenced systems to develop computer-automated databases that can make map data more flexible and accessible in evaluating proposed projects and programs. A study group should consider the costs and benefits of coordinating state efforts to improve compatibility, assisting in the development and use of such digital databases, and providing or maintaining a central repository of, and access to, digital data of coastal habitat types.

Inventories of Other Habitat Types. NWI maps are of limited use for some types of habitats other than vegetated wetlands or marshes. Better inventories of selected subtidal habitats, such as shellfish beds, submerged aquatic vegetation, and hard bottoms, and endangered species habitats should be made available.

Document Trends. Ongoing and planned work at the national level to document trends in wetlands loss appear to be adequate and should be continued.

Causes of Habitat Loss

The following work would provide better information on the causes of habitat loss and modification, primarily for emergent and submerged aquatic vegetation.

Identification of Causes. National/regional analyses of the human activities that cause habitat loss could provide useful information. Such analyses could be conducted to identify and quantify human activities causing physical alterations that directly or indirectly result in habitat loss and modification. Such a task would be labor intensive. A cost/benefit assessment of this approach would be the logical first step.

Natural Processes and Habitat Functions

The following work would improve our basic understanding of natural processes that affect habitat functions and values and the mechanisms by which human activities alter these functions.

Link to Living Marine Resources. Research to improve our understanding of the habitat processes and functions as related to living marine resource productivity and the effects of human activities on these processes and functions would be useful. Specifically, we need a better understanding of the long-term effects of specific projects as well as the cumulative effects on a regional basis.

Effects of Sea-Level Rise and Geological Processes. Development of models to assist in predicting the effects of sea-level rise on marine and estuarine habitats would enhance our ability to predict these effects. Models could also be developed to predict changes in geologic processes (accretion, erosion, and sedimentation) affecting habitat that result from human activities.

Mitigation

Work in the following area would improve our ability to mitigate the effects of habitat loss.

Mitigation Assessment. Approaches should be developed and implemented for assessing the effectiveness of mitigation and restoration techniques in terms of the quality of the restored habitat.

Marine Debris

The following work would help to adequately address the problems associated with persistent marine debris in the marine environment.

Sources. Research to determine the level of land-based contributions to the marine debris problem would help quantify sources.

Effects. Research to identify and quantify the effects of marine debris should focus on populations of fish and wildlife, coastal communities, and vessels. Information is also needed concerning degradable plastics to determine their environmental effects and potential applications.

Monitoring. Monitoring would help to determine the rates of marine debris entanglement and ingestion by wildlife. Emphasis should be placed on endangered or threatened species, vessel disablement, and coastal wash-up events to determine the effectiveness of MARPOL Annex V and degradable plastic products.

Development. Techniques should be developed to reduce the impact of fishing gear entanglement through loss prevention and recovery incentives, recycling, and the use of degradable plastics technology for fish traps and pots. Methods should also be developed for the handling and storage of ship-generated waste and the reduction of land sources of marine debris.

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GOAL 5: DOCUMENT THE TRENDS IN THE STATUS OF MARINE ECOSYSTEMS

Oceanic, coastal marine, and Great Lakes waters support a wealth of living resoures, provide aesthetically pleasing recreational opportunities, and sustain many commercial enterprises. These valuable waters also receive the waste products of human activities through terrestrial run-off, waste discharges into rivers, estuaries and marine ecosystems, and atmospheric deposition. Coastal and estuarine environments are also subject to physical disruptions associated with human activities, which may result in the loss or deterioration of important habitats. Competition for use of these waters will increase as our population continues to shift to the coastal zone. Due to the increasing human activity in coastal areas and demand for marine resources, the capacity to assess conditions and trends in the quality of marine ecosystems and to be aware of early warning signals of unacceptable conditions is important. Therefore, documenting the trends in the status of marine ecosystems is an important goal of the National Marine Pollution Program.

Goal Definition

Under conventional regulatory strategies, attempts are made to manage each use of the marine environment individually so that conflicts with other valued uses are minimized or avoided. Yet, because the cumulative effects of different human activities are difficult to foresee, it is not possible to predict with confidence the effects of human activities on the marine environment. However, monitoring environmental conditions and trends within marine ecosystems can provide early warning signals of potential pollution effects and generate information needed to avoid or remediate unreasonable or socially unacceptable degradation. Unfortunately, at this time there are significant gaps in our understanding of the relationships between the condition of marine ecosystems and the parameters that can be measured in marine environments. These uncertainties are further complicated by natural variations in time and space for which many components of marine ecosystems are notorious. However, these variations do not necessarily prevent detection of pollution effects, as has been demonstrated by studies in many industrialized estuaries of the nation and in the Great Lakes.

It is not feasible to discuss conditions and trends in the quality of marine ecosystems without defining "monitoring." For the purposes of this goal, "monitoring" is defined according to NOAA (1979): "Monitoring is the continued, systematic time-series observation of pre-determined pollutants or pertinent components of the marine ecosystem over a period of time sufficient to determine (1) the existing level, (2) trends, and (3) natural variations of measured components." Data obtained through such observations can be used most effectively by environmental managers if monitoring programs have specific objectives that provide the managers with the information necessary to make informed decisions. This would require levels of environmental quality to be pre-defined as "acceptable" or "unacceptable" (Segar and Stamman, 1986). Two types of monitoring programs are defined by NOAA (1985): monitoring inputs and near-field effects of potential sources of pollution (including compliance monitoring), and monitoring the general condition of marine resources through indicators of ecosystem or resource status. For the purposes of this Plan, the former is considered near-field monitoring and the latter far-field monitoring.

This goal is concerned with broad, far-field monitoring required to establish present conditions of the ecosystem and to follow long-term trends on a regional scale. This involves developing and detecting early warning signs of potential pollution problems and following trends to show how the ecosystem's status is changing. Initially, the goal is not to establish causes and sources; these would be investigated through more comprehensive diagnostic studies after a problem is identified. Research priorities for such diagnostic studies are discussed in this Plan under National Marine Pollution Program Goals 1 through 4.

Regulatory compliance monitoring that addresses specific sources of pollution is pertinent to this goal when it is possible to integrate near-field and far-field activities. Monitoring methods that are effective in identifying problem areas around marine discharge and disposal sites in fact measure symptoms of poor marine ecosystem status. Symptoms of deterioration in status may be more easily recognized and agreed upon within impacted marine ecosystems than are far-field measures of ecosystem health (Phelps, 1988).

Much data and information have been published in the past regarding the status of marine ecosystems obtained by measuring contaminants in specific ecosystem components. Data obtained through monitoring waters receiving industrial and domestic effluents (compliance monitoring) make up a large portion of the database. Some monitoring studies document levels of PCBs, DDT, and chlorinated hydrocarbons in fish and invertebrates (NOAA, 1986a). Other databases record levels of metals in benthic biota and fishery organisms. Such historical or "encountered" data are generally helpful in interpreting recent monitoring data. Historical data also can be used to verify environmental models if assumptions and uncertainties are carefully considered.

The scope of monitoring diverse aspects of marine ecosystems requires cooperative efforts among Federal, state, and local scientists and managers. A consensus of marine pollution managers from all regions of the United States suggests that the most effective monitoring activities occur at the regional level and national monitoring programs should be the sum of regionally planned programs coordinated at the national level (Segar, 1981). Examples where Federal agencies and programs interface well with regional activities and facilitate the exchange of information include the NOAA, EPA, and Coast Guard Accidental Spills Scientific Response Programs (National Contingency Plan); the NMFS Fishery Centers' regional research program (NOAA, 1986c); EPA's National Estuary Program; and EPA's Regional Offices' interactions concerning discharge permits and compliance monitoring.

Selection, testing, and application of various indicators of the quality of marine ecosystems are of the utmost importance in establishing conditions and trends in these ecosystems. Close collaboration between scientists and managers is necessary to ensure that monitored measures of environmental quality are truly useful for managerial decisions, and that these interpretations are seen as informative. Numerous studies have developed indices for specific monitoring purposes (Farrington et al. 1983; Phillips and Segar, 1986; and Dames and Moore, 1984). The Food and Agricultural Organization (FAO) sponsored a workshop to evaluate indices for measuring response of ecological systems and to emphasize indices that could discriminate among natural factors and fishery exploitation (FAO, 1976). The necessity of matching indices of marine environmental quality with management needs was discussed by Wolfe and O'Connor (1986). They also suggested that environmental parameters for establishing trends could be expressed most informatively relative to normal values accounting for variability in measurement. O'Connor et al. (1987) constructed an index to detect above-normal disease prevalence in fish and shellfish that warrants a warning or alarm for management purposes.

Monitoring programs are not a panacea in that they cannot "be all things for all people" (Farrington et al., 1983; Phelps, 1988). The selection of specific parameters for measurement depends upon the purposes and goals of the particular monitoring program. To be effective in addressing this goal of the National Program, a monitoring program may require measurements of physical and chemical factors correlated with human activities as well as biological responses to human influence (e.g., histopathological disorders). This section is a discussion of the potentialities and limitations associated with the current state-of-the-art in monitoring the status of marine ecosystems and an evaluation of how well Federal programs are addressing this goal.

Federal Role

Presented below is a discussion of the Federal legislation and programs that address the issue of the status and trends of marine ecosystems. Additional information concerning the Federal programs addressing specific information needs are presented in the discussions of the management questions. More detailed information on the Federal programs and projects that address the issue of marine monitoring can be found in the National Marine Pollution Program, Summary of Federal Programs and Projects (NOAA, 1987c).

Federal Legislation and Regulations

The Federal Water Pollution Control Act (FWPCA) amendments of 1987 (§ 320(j)(1)) mandate that EPA shall coordinate and implement the following through NOAA for one or more estuarine zones:

(A) A long-term program of trend assessment monitoring measuring variations in pollutant concentrations, marine ecology, and other physical or biological environment parameters....

(B) A program of ecosystem assessment assisting in the development of (i) baseline studies which determine the state of estuarine zones and the effects of natural and anthropogenic changes, and (ii) predictive models....

(C) A comprehensive water quality sampling program for the continuous monitoring of nutrients, chlorine, acid precipitation, dissolved oxygen, and potentially toxic pollutants....

(D) A program of research to identify the movements of nutrients, sediments and pollutants through estuarine zones and the impact of nutrients, sediments, and pollutants on water quality, the ecosystem, and designated or potential uses of the estuarine zones.

Prior to 1987, the most direct mandate to monitor marine pollution was contained in the earlier version of FWPCA, which states that EPA, in cooperation with other Federal agencies shall "establish . . . and maintain a water quality surveillance system for the purpose of monitoring the quality of the navigable waters . . . of the contiguous zone and the oceans . . . "(33 U.S.C. 1254 (a)(5)). In regulations developed pursuant to the FWPCA, EPA has established guidelines for monitoring programs that must be conducted by dischargers releasing point source (pipeline) effluents into surface waters. Section 1315(b)(1) mandates that each state prepare a report biennially that shall include a description of the State's water quality.

Section 201 of the Marine Protection, Research and Sanctuaries Act (MPRSA) requires NOAA, in coordination with EPA and the U.S. Coast Guard, to "initiate a comprehensive and continuing program of monitoring and research regarding the effects of the dumping of material into ocean waters . . . or the Great Lakes . . . " (33 U.S.C. 1441). Section 202 of MPRSA (also known as the Ocean Dumping Act) also requires NOAA to conduct a "comprehensive and continuing program of research with respect to the possible long-range effects of pollution, overfishing, and man-induced changes in ocean ecosystems" (33 U.S.C. 1442). Although this mandate calls for "research," some of the activities required fall within the definition of monitoring adopted in the National Ocean Pollution Planning Act, which requires NOAA to . . . "establish . . . a comprehensive, coordinated, and effective ocean pollution research and development and monitoring program" (33 U.S.C. 1704).

The Outer Continental Shelf Lands Act requires the Minerals Management Service to "monitor the human, marine, and coastal environments of such areas or regions (OCS oil and gas leasing areas) in a manner designed to provide time-series and data trend information which can be used for . . . the purpose of identifying any significant changes in quality and productivity of such environments, for establishing trends in the areas studied and monitored, and for designing experiments to identify the causes of such changes" (43 U.S.C. 1346).

Remaining mandates related to monitoring of pollution in the ocean and Great Lakes are less direct. For example, the USGS has been given responsibility under several legislative mandates for performing hydrologic investigations of water in streams and underground.

Federal Programs

Several Federal agencies conduct marine monitoring activities. Most, however, are sponsored by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce and the Environmental Protection Agency (EPA). The following discussion is a summary of the types of monitoring activities supported by these agencies.

The National Marine Fisheries Service (NMFS) and the Ocean Assessments Division (OAD) of the National Ocean Service conduct most of the monitoring activities of NOAA. The OAD's major monitoring effort is the National Status and Trends Program. Under this program, OAD annually collects bivalve molluscs, bottom-feeding fish, and surface sediments from 200 sampling stations along the U.S. coast. These samples are then analyzed for contaminants, as well as histopathological and other disorders in the fish and shellfish. The NMFS monitors and documents the status and long-term changes in fish/shellfish health and environmental quality to generate information for developing and testing hypotheses that relate environmental quality to the health of living marine resources. These monitoring activities are conducted in selected estuarine and coastal areas as well as at ocean disposal sites. The NMFS also supports the Microconstituents Program, which monitors contaminant levels in marketplace fish.

The EPA's marine monitoring activities are conducted by its Environmental Research Laboratories and through the agency's National Estuary Program. The agency develops monitoring technologies, produces guidance documents for monitoring ocean dumpsites, and provides technical assistance to industry for establishing field monitoring programs. The EPA develops and verifies chemical and biological methods to determine the bioaccumulation potential of contaminants in waste to be disposed of in the ocean and to determine the biological significance of contaminant levels in tissue. The EPA also conducts site-specific assessments of ocean disposal sites, which include surveys of biological, water, and sediment samples followed by assessments of environmental effects that result from use of the sites. In the Great Lakes region, EPA supports an extensive monitoring program. Activities include monitoring of municipal water intakes for water quality and biotic structure and function; atmospheric loadings of metals and nutrients; and sediment, water, and biological samples in various sites throughout the Great Lakes to assess environmental quality. Under its National Estuary Program, the agency funds efforts to characterize current conditions and historical trends of priority problems in specific estuaries.

Other Federal agencies that conduct marine pollution monitoring include the Minerals Management Service (MMS), U.S. Fish and Wildlife Service (FWS), and U.S. Geological Survey (USGS) of the U.S. Department of the Interior; the Food and Drug Administration (FDA) of the U.S. Department of Health and Human Services; and the U.S. Army Corps of Engineers (COE) of the U.S. Department of Defense. The MMS's regional offices support monitoring activities to assess potential changes in marine environments that are a result of Outer Continental Shelf oil and gas development and production activities. The FWS annually monitors trends in levels of organochloride pesticides and related compounds in wetland bird species in sites along major North American flyways. The FWS also monitors levels of organochlorine compounds and trace metals found in bottom-feeding and predatory freshwater fish species, some of which inhabit estuarine waters. The USGS monitors water quality parameters including suspended solids, toxic metals, and toxic organics at selected downstream sites located at river mouths. The FDA monitors the levels of toxics, contaminants, or bacteria in finfish and shellfish to determine the incidence of these pollutants in seafood. The COE conducts monitoring activities to evaluate the impacts of various coastal construction activities, to provide baseline environmental information on dredged material disposal sites, and to provide long-term assessments of the impact of dredged material disposal.

Management Questions and Information Needs

The most direct measures of ecosystem conditions are biological responses to human influence. Examples of biological responses that might be monitored in marine systems include mortality rate, population size, reproductive success, developmental abnormalities, metabolic activity, changes in primary and secondary productivity, and changes in community structure. In the following discussions, it is assumed that two types of parameters should be considered for monitoring efforts to meet these goals: 1) measures of biological response to human influences, and 2) physical and chemical factors of ecological significance that are altered as a consequence of human activity. The management questions below have been developed to help organize the discussion of research and monitoring needs:

Management Question 1: What is the status of marine ecosystems as indicated by biological responses to human influences? How is the status changing?

Management Question 2: How are physical and chemical factors that affect biological responses changing spatially and temporally?

This section includes an evaluation of how well marine ecosystem monitoring programs can address these management questions and a discussion of the adequacy of existing information. Recommendations are made as to the types of research, development, and monitoring work that would most effectively improve our information on the environmental status of marine ecosystems.

Changes in Biological Status

Management Question 1: What is the status of marine ecosystems as indicated by biologic responses to human influences? How is the status changing?

Information Needs

1a. What are the physiological and biochemical indicators of anthropogenic stress in marine organisms? How are they changing?

1b. How are populations and communities affected by anthropogenic stress?

1a. What are the physiological and biochemical indicators of anthropogenic stress in marine organisms? How are they changing?

Physiological characteristics of many estuarine organisms allow them to adapt to the rigors of dynamic environments where there are large fluctuations in temperature, salinity, and other parameters. Unfortunately, it is often difficult to separate physiological responses to natural stress from effects of pollution stresses, but certain changes within organisms are specific to a pollutant or type of pollutant. Physiological responses to pollutants include changes in metabolism, body fluids, and tissues. Tissue changes may be in the form of lesions, tumors, and other histopathological manifestations. These physiological and histopathological changes often precede mortality as an overt sign of toxicity (Mehrle and Mayer, 1985; Meyers and Hendricks, 1985). Some promising indicators of pollution stress also are found at the molecular and genetic levels (Dames and Moore, 1984).

Several measures of the general response to stress such as "scope-for-growth" (index of the amount of energy an animal requires for growth) (Warren and Davis, 1967), growth inhibition (Sanders and Jenkins, 1984), and stress protein response (Tanquay, 1983) have been identified. Also, a number of stressor-specific responses have been developed such as induced production of certain proteins such as metallothioneins (metal-binding proteins) and mixed-function oxidases, and accumulation of metals in metallothioneins and very low-molecular-weight ligand pools (Jenkins and Sanders, 1986). Such responses to stress show promise as effective indicators of marine pollution. However, these measures of biological response require further testing and development before they could be used and integrated with confidence.

An important emerging area for research involves work to adapt, calibrate, and validate short-term genotoxicity tests in fish for the assessment of genetic hazards associated with hazardous substances, and to examine the relationship between environmental exposure, metabolism, and activation of promutagens, DNA-binding, and mutational events occurring in somatic cells of different biomonitor species. Promising genotoxicity assays have been demonstrated using chromosomal aberration, micronuclei, and sister chromatid exchanges as endpoints. This work has particular ecological relevance when it is focused upon early developmental stages of aquatic organisms.

Histopathological indicators of disorders in fishes have been used in monitoring studies conducted by NOAA (1986b; 1987d). Observations on Atlantic croakers from seven benthic surveillance sites showed a positive correlation between concentrations of aromatic hydrocarbons in sediments and occurrences of selected histopathological disorders. In other studies, Malins et al. (1984) discuss the relationship between chemical pollutants in sediments and disease of bottom-dwelling fish in Puget Sound, Washington. Patton and Couch (1984) present hypothetical correlations of lesions and pollution. Couch suggests that kepone in the James River contributed to fish kills by causing scoliosis, a lateral deviation of the spine. An index of pollutant-induced fin rot disease in winter flounder was developed by O'Connor et al. (1987).

The EPA, in cooperation with the COE, employed a comprehensive field program to evaluate methods for determining the effects of dredged material disposal in a marine environment (Phelps et al., 1987). Several physiological measures of mussels were made including sister chromatid exchange (exchange of chromosome parts known to increase in frequency in stressed organisms), adenylate energy change (change in the relative energy state of the cell), metallothionein induction, and growth. Growth was significantly reduced at disposal sites when compared to "control areas," and metallothionein levels appeared to be elevated at disposal sites, but this difference was not statistically significant.

A number of stress responses at the organism and suborganism level have been identified and tested as indicators of pollution. Some of these would provide useful information if included in a monitoring program at this time; many show great potential but need further development. To improve our ability to identify and evaluate pollution stress in marine organisms, work should continue to develop and field test the most promising of these indicators.

1b. How are populations and communities affected by anthropogenic stress?

Marine ecosystems are complex entities composed of interacting biotic and abiotic components. The exposure of ecosystems to stress is complex and may affect structural and functional aspects differently. The structure (manner in which plants and animals are organized within an ecosystem) of a marine ecosystem can be changed by anthropogenic influence. These changes can be measured through indices such as species diversity, density, and richness; relative abundance; and dominance index (Swartz et al., 1985). These and other indices of structural change when viewed together reflect in part the status of an ecosystem. Changes may be based on comparisons with "control" or reference areas, or determined through time trend analysis of a specific system. Such comparisons, however, are limited by our understanding of natural variability in marine ecosystems.

Changes in community structure have been used in the past to indicate the status of marine ecosystems (Pearson and Rosenberg, 1978; Gannon et al., 1986; Swartz et al.,1985; Phelps et al., 1987). Long-term measurements of population abundance of infaunal invertebrates and fishes in a mesohaline portion of the Chesapeake Bay provided valuable base-line data on "natural" variations in population abundance (Hines et al., 1987). A 35-year study on the benthic infaunal invertebrate populations in Los Angeles-Long Beach Harbors demonstrated an improvement of ecological conditions as a result of pollution abatement (Reish, 1986). Changes in the structure of benthic infaunal populations associated with a seagrass community exposed to drilling fluids containing diesel oil were noted in laboratory microcosm studies (Morton et al., 1986; Kelly et al., 1987). Drilling fluids in the microcosms significantly reduced richness indices based on species number and density of individuals.

Functional integrity is required for maintenance of any ecosystem. Functional aspects include movements and transformations of chemicals and energy which in turn support biological communities. Ecosystem productivity is a basic function that may be used to monitor the status of the system. Primary production can determine the amount of living tissue an ecosystem can support (Woodwell and Botkin, 1970). Thus, in some instances, it may be important to detect changes in primary production. Several marine studies used primary production as an index of the quality of an ecosystem (Smayda, 1984; Fay et al., 1986). The rate at which estuarine organisms decomposed plant material was one indication of adverse effects of drilling fluids on a seagrass system (Morton et al., 1986). Also, naturally occurring bacterial communities may provide a means for detecting changes in ecosystem status. Singleton et al. (1984) found significant changes in bacterial community composition in surface waters near Puerto Rico due to the introduction of pharmaceutical wastes.

Other indicators can be used to evaluate the impact of stress on an ecosystem and determine the response of the system. Harwell et al. (1987) discussed the impact of stress on an ecosystem and its responses:

> "In summary, the effect of a stress on an ecosystem is a function of the frequency, duration, and intensity of the stress; its similarity to natural stresses to which the ecosystem has had a history of exposure; the spatial extent of the stress; and the nature of both the stress and the ecosystem. Simple generalities of responses of ecosystems to stresses are not realistic; however, it may be possible to develop a complex paradigm of ecosystem stress-response relationships, aggregated both by ecosystem type and the nature of the stress."

These authors explain that no single parameter will suffice as an indicator of system-level stress responses and that every detectable change does not necessarily indicate a change in the health of the system. However, a change in the state of a system may be more important than the state of the system itself.

Although structural and functional measurements can provide resource managers with helpful data, these endpoints have not been widely used in monitoring programs. One reason is a lack of basic understanding of what changes in the measurements of structure and function mean in relation to the quality of the ecosystem. There is a gap in information concerning the relationships among specific levels of contaminants in communities, structural effects on the community, and relationships of the changed community to the health of the ecosystem.

In order to understand function and structure of marine ecosystems, it is necessary to conduct long-term studies of these ecosystems. One of the difficulties in conducting long-term ecological research is that ecological research (as well as many other research activities) traditionally has been funded for short periods of time. The National Science Foundation's Long-Term Ecological Research Program (LTER) was established to alleviate this situation (Callahan, 1984). This long-term research program is oriented toward question/hypothesis formulation and resolution. The research is not necessarily based on a trophic structural approach but is organized around families of structural and functional attributes. The program is designed so that 11 chosen sites represent samples of the ecosystems of the United States. Two of the sites are concerned with the coastal environment. The North Inlet Marsh-Estuarine study in North Inlet, South Carolina examines the biological, chemical, and physical aspects of the system including life histories, patterns of organisms, primary production rates, and physical-chemical measurements of the water column. The Virginia Barrier Island-Estuarine Site on the Delmarva Peninsula encompasses observations on changes in landmass of the islands and marshes, changes in composition of the landscape, biota, and changes in such processes as productivity, decomposition, and sediment deposition.

A wide variety of indicators of human influence at the population, community, and ecosystem levels have been developed and tested for marine systems in the past, and the International Joint Commission is currently using lake trout as an indicator of ecosystem status in the Great Lakes. Difficulties associated with these techniques include partitioning natural fluctuations from pollution effects and determining when observed changes or differences are of concern. Despite these limitations, parameters measured at these higher levels of biological organization should be considered for a comprehensive surveillance program to meet this goal of the National Program. Basic research and development activities should be continued to increase the utility of these indicators.

Changes in Physical and Chemical Factors

Management Question 2: How are physical and chemical factors that affect biological responses changing spatially and temporally?

Information Needs

2a. What concentrations of chemical contaminants occur in selected marine ecosystems components (water, sediment, and biota)? How are these levels changing?

2b. How are hydrographic factors such as freshwater inflow, dissolved oxygen concentration, and sediment loadings changing spatially and temporally?

2a. What concentrations of chemical contaminants occur in selected marine ecosystems components (water, sediment, biota)? How are these levels changing?

The capacity for this country to fully use and manage living marine resources depends to a great extent upon resource managers' knowledge of concentrations of pollutants in the water, sediment, and biota of marine ecosystems; changes in these concentrations; and the effects of these levels of contaminants on resources and ecosystems in which they occur. Managers must be aware of trends in these levels in order to assess the impact of human activity on marine resources and to develop options for improving the quality of marine ecosystems. Information on concentrations of contaminants without corresponding information on effects severely limits the use of monitoring data. However, for discussion purposes, concentrations in components of ecosystems are separated from effects on the ecosystems. Persistence, degradation rates, and biogeochemical cycling of contaminants within the sediments, and the flux of those contaminants between sediments, water, and biota are critical to understanding the implications of human influences on marine systems (Capuzzo, 1988). These topics are discussed in this Plan under National Marine Pollution Program Goal 1 and are beyond the scope of the discussion in this section. For monitoring purposes, concentrations of selected contaminants in marine and Great Lakes ecosystems are considered as indicators or signals of possible pollution problems.

Concentrations of pollutants in water are usually the primary focus of compliance monitoring programs such as those associated with the National Pollution Discharge Elimination System (NPDES) permitting system. In this program, permits often are issued on the condition of not exceeding specified concentrations of chemicals in receiving waters. Data developed in these compliance monitoring programs are sometimes of utility to far-field monitoring activities because regulatory limits in water quality permits are usually based on the adverse effects of the materials being monitored to sensitive life stages of marine organisms. Chemicals appearing in high concentrations in the near-field can alert managers to potential adverse impacts on resources in adjacent or far-field waters or systems. However, many chemicals are found in much higher concentrations in sediment and biota than in water.

Contaminant concentrations in sediments are measured because sediments often serve as a reservoir for many pollutants and can be a conduit for transferring pollutants associated with the sediment to bottom-feeding organisms and, under certain circumstances, for cycling pollutants back into the water column. Furthermore, benthic organisms have been found to accumulate metals and organics to concentrations many times above levels found in the sediment in which they live (NOAA, 1987d; Young et al., 1981). This is especially true in low-energy depositional areas where sediments are accumulated and deposited over time. The

National Status and Trends Program (NOAA, 1986b; 1987d) provides data on metal and organic contamination of sediment in selected sites, and in some instances, scientists have related contaminant levels in the sediment to levels in biological tissues. Radiometric and chemical analyses can provide a time-integrated record of pollutant deposits where natural strata of sediment deposition are preserved (Bopp et al., 1983; Koide et al., 1973).

Biota can concentrate many contaminants above levels found in water and sediment; therefore, concentrations of contaminants in tissues are an important indicator of the occurrence of a contaminant in the ecosystem. Organisms with high contaminant body burdens represent a concentrated exposure medium to higher trophic levels in the ecosystem. Contamination levels in seafood are of particular interest because, should the levels exceed limits established by FDA for human consumption, an entire fishery could be adversely affected economically and human health could be threatened (see Goal 6 for a discussion of research needs related to human health). However, the FDA limits do not necessarily address the question of effects on the seafood organism. Unfortunately, because of the vast number and various life-stages of marine organisms, the relationship between contamination levels and effects on contaminated organisms may not be as clear as the seafood-to-people example. Consequently, body-burden data are often of limited use to resource managers, and these data can be extrapolated to effects only when appropriate research information is available. Biological response measurements can be made in conjunction with residue analyses to indicate exposure to contaminants. These response measurements are especially helpful in detecting exposure of organisms to rapidly transformed chemical compounds such as organophosphate pesticides.

As indicated in the Federal Programs part of this section, the Federal Government supports monitoring programs to evaluate the levels of contaminants in marine ecosystems. Since 1984, NOAA has conducted the National Status and Trends Program to develop information on the status and trends of environmental quality in marine waters (Ehler and Calder, 1986). The EPA continues a monitoring program to determine contaminant loading in the Chesapeake Bay in cooperation with the states of Maryland and Virginia. In 1984, a 167-station monitoring network was established in the bay to define trends in water and sediment quality (Mountford and Mackiernan, 1987). The USGS also monitors water quality of coastal waters in relation to their stream monitoring programs. Although chiefly a freshwater monitoring program, the FWS's National Fish Monitoring Program includes some estuarine species. The Minerals Management Service's Environmental Studies Program supports monitoring activities to identify and establish trends in changes in the quality of OCS environments resulting from offshore oil and gas activities. Recently, the FDA, NOAA, and EPA cooperated in surveying levels of PCBs in bluefish from the Atlantic coast (NOAA, 1986c). This is an example of a relatively short-term, mission-oriented monitoring program often required of Federal agencies.

Many state and local monitoring programs are conducted and supply valuable monitoring data for assessment purposes. For example, the State of Florida is involved in an estuarine monitoring program that encompasses improving reliability of estuarine data, establishing and extending the chemical database, and improving tools for assessing estuarine pollution (Calder, 1988). Other examples of local monitoring activities include studies on many bays and estuaries such as the one conducted on variations and long-term changes in Narragansett Bay in relation to phytoplankton population and nutrient concentration by Smayda (1984). Because so many monitoring programs have already been completed and others are ongoing, there is a need to evaluate and where possible use historical or "encountered" data and to coordinate ongoing and future monitoring activities.

Although much historical data on residues of chemicals in marine waters, sediment, and biota are available, few of these data were collected so that trends could be established. NOAA's Status and Trends Program was established as an initial step to correct this shortcoming. The program is designed to answer such questions as: Are general conditions getting better or worse? How do conditions in different areas compare? Two major field sampling projects were established to help obtain answers to these questions. One aspect of the program is to acquire relevant data from other sources such as past monitoring programs and ongoing regional ones. Data are available from the Status and Trends Program on concentrations of chlorinated pesticides, PAHs, PCBs, and trace metals in marine and estuarine fish, bivalves, and sediments (NOAA, 1986a). The Status and Trends Program has two components; the Benthic Surveillance Project and Muscle Watch Program. The Benthic Surveillance Project provides data on fish pathology and chemical analyses of fish livers and sediment from 50 sites. The Muscle Watch Program provides data on chemical and histological analyses of marine molluscs from 150 sites (NOAA, 1987d).

Results obtained from monitoring studies indicate that it is feasible and useful to document status and trends of contaminant levels in living and nonliving components of marine ecosystems. Measurements of contaminants in water, sediment, and biota should be made only to the extent that they contribute information needed for environmental decision making. Additional summaries of historical contaminant concentrations will generally be necessary to interpret recent measurements. Both sets of activities would require aggressive coordination of significant monitoring programs sponsored by Federal, state, and local governments.

2b. How are hydrographic factors such as freshwater inflow, dissolved oxygen concentration, and sediment loading changing spatially and temporally?

Hydrographic factors are of fundamental importance to the functioning of estuarine and coastal ecosystems. For example, the recruitment of many fish and shellfish stocks is closely linked to the hydrodynamics of estuaries and associated coastal waters. Changes in hydrographic conditions can result in changes in the production, composition, and abundance of phytoplankton, and reduction in the abundance and extent of desirable rooted aquatic vegetation. These changes can be associated with decreased dissolved oxygen and light penetration. Such alterations can be detrimental to the production of estuarine-dependent organisms through shifts in food resources and changes in the availability of suitable habitat (NOAA, 1987b).

The quality and quantity of freshwater inflow into a coastal area or estuary can greatly impact biogeochemical cycles within the zone. Water laden with nutrients, sediments, and toxicants can influence biological and hydrographical regimes. Decreases in flow can cause saltwater intrusion that can result in changes in circulatory patterns and can alter circulation to the point of shifting conditions normally found at the outlet of an estuary to positions nearer the river input. Conversely, increases in flow can shift conditions in the opposite direction toward the inlet. Altered salinity can affect the distribution and composition of phytoplankton (Soniat and Boesch, In press). Increases in salinity can cause osmotic regulation problems for those species that must prevent dilution of their cell content. Decreases in salinity are tolerated by only the euryhaline forms. The impact of freshwater inflow on fish populations in Faka Union Bay was studied by the National Marine Fisheries Service (Beaufort Laboratory, 1984). When compared with fish from similar, unimpacted marine areas, Faka Bay fish were less abundant. Invertebrate communities, including shrimp and crabs, showed lowered overall abundance.

In a nationwide study conducted for NOAA, hypoxic areas were identified in 126 of 131 coastal and estuarine waters for which adequate data exist (Whitledge, 1985). In the Great Lakes, of 42 identified locations of concern, 21 showed oxygen depletion associated with eutrophication (GLWQB, 1987). Major losses of coastal and estuarine living space during the productive summer months by hypoxic/anoxic conditions have been implicated in losses of major fisheries such as striped bass. Coutant (1987) suggested that anoxia in nutrient-enriched estuaries has had detrimental consequences for the ability of striped bass to reproduce. There is also evidence to suggest that severe hypoxic conditions result in mass mortalities among shellfish and some bottom-dwelling finfish species, which can result in loss of fish catch and increased ecological stress by the decay of the affected fish population (NOAA, 1987a).

Changes in suspended sediment loads have occurred in many areas of the country as a result of changes in freshwater input, dredging and other coastal construction activities, and agricultural practices. Increased sediment loads can have negative impacts on marine and estuarine habitats through shoaling, which can decrease the volume of an estuary and result in a decrease or change in habitat (such as the burial of oyster cultch materials). Increased suspended sediments may also affect primary productivity due to its effect on light attenuation. In a study of the Delaware Estuary, Pennock (1985) found an inverse relationship between suspended sediment loads and chlorophyll concentrations. The author concluded that the predominant physical factor regulating phytoplankton biomass was suspended-sediment concentration.

Data on basic hydrographic factors such as freshwater inflow and sediment loadings are generally already available for major estuarine and coastal systems; or could be collected at a relatively low cost. Although there are gaps in our knowledge concerning the impact of hydrographic factors on marine ecosystems, inclusion of certain hydrographic factors in a surveillance monitoring program would provide useful information. Major changes in these factors could signal impending threats to valued resources and indicate that further investigation would be prudent. More basic research in the following areas would be especially valuable in judging the significance of changes in hydrographic parameters: effects of changes in freshwater inflow on secondary productivity, relationships between freshwater inflow and low dissolved-oxygen and pollutant concentrations, effects of land-use changes on sediment loadings, and effects of sediment loadings on secondary productivity.

Conclusions and Recommendations

An explicit mandate has been developed by Congress for the collection of fundamental information on the status of marine ecosystems with respect to pollution effects. The technological capability exists to perform such monitoring, and ongoing Federal programs have made progress toward satisfying this mandate. A national program to fully address this mandate should take advantage of historical data and include a coordination and standardization component to promote the most effective use of ongoing state and local sampling programs. Federal monitoring efforts should be designed only to provide needed information that is not available from other sources. Although a general framework or strategy for such a program would be best developed at the national level, evaluations of ecosystem status would need to be adapted to each region so that the special attributes and problems of the region could be considered. In designing a program to monitor the status of marine ecosystems, parameters from four categories should be considered. Listed below is a synopsis of the potential and limitations of parameters in each category as well as suggestions for research and development work that would increase the utility of these indicators.

Organism Responses. A number of indicators of pollution stress on individual organisms (e.g., "scope-for-growth," growth inhibition, stress protein response) show potential for use in marine monitoring programs, while others need further development. Work should continue to develop and field test the most promising of these indicators.

Population and Community Responses. Indicators of pollution stress at the population and community levels have been developed for marine systems (e.g., species diversity, density, and richness; relative abundance; and productivity). However, these techniques often cannot adequately distinguish between natural changes and pollution effects or determine when observed changes are significant. Basic research and development activities designed to increase the utility of these indicators should continue.

Concentrations of Contaminants. Measurements of contaminant-level trends in water, sediment, and biota provide resource managers and decision makers with useful and necessary information. Having these measurements may provide clues to the cause of any adverse biological effect. Summaries of historical contaminant concentrations should be developed to compare to recent measurements.

Hydrographic Factors. Data on hydrographic factors are generally available for many coastal areas and can be incorporated as part of monitoring programs. Additional research is needed in the following areas to provide necessary information concerning the significance of changes in hydrographical parameters:

- Effects of changes in freshwater inflow on secondary productivity;
- Relationship between freshwater inflow and low dissolved-oxygen and pollutant concentrations;
- Effects of land-use changes on sediment loading; and
- Effects of sediment loadings on secondary productivity.

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GOAL 6: UNDERSTAND THE IMPLICATIONS OF MARINE POLLUTION TO HUMAN HEALTH

Human health concerns related to marine pollution center on toxic substances and pathogenic microorganisms that are introduced into marine ecosystems as a result of human activities. Typical routes of human exposure include consumption of seafood and swimming. Although acute toxic responses have not been reported to result from consumption of chemical contaminants in U.S. seafood, synthetic organic compounds and metals have been found in marine species harvested for human consumption from some areas. In addition, seafood may contain pathogenic microorganisms as a result of harvesting seafood from sewage-contaminated areas, from certain human pathogens that occur naturally in the marine environment, or from contamination that occurs during improper processing or shipping of seafood products. Governmental programs, such as the National Shellfish Sanitation Program, have been effective in protecting the public from major outbreaks of disease. Important public health concerns related to marine pollution remain to be addressed, including sporadic outbreaks of gastroenteritis caused by viruses and any latent effects that may result from chronic exposure over long periods of time to chemical contaminants in seafood. Therefore, understanding the implications of marine pollution to human health is one of the six goals to the National Marine Pollution Program.

Goal Definition

A number of pollutants have been identified in the marine environment that can cause adverse human health effects. Although the presence of these agents in the marine environment does not alone constitute a public health risk, some health risk may result if human exposure exceeds threshold levels of these agents. Adverse health effects from these substances arise from either the toxicity or pathogenicity of the agent and the extent to which the population is exposed. A goal of the National Marine Pollution Program is to understand better the relationship between exposure of humans to pollutants in the marine environment and the risk of developing an adverse health effect. To address this goal, it would be logical to characterize the toxicity, pathogenicity, and human exposure to marine pollutants. The management questions in this section are structured around the information needs related to these topics. Also addressed in this section are the current efforts to generate the needed information and recommendations to fill the important existing data gaps.

The pollutants of concern with regard to human health effects that are discussed in this section of the Plan can be broadly grouped into two categories: chemical contaminants and human pathogens. Substances in these categories are of concern because they (1) are known to be present in the marine environment, (2) have the potential to come into contact with human populations, and (3) are known to cause various adverse effects such as birth defects, cancer, liver disease, neurological disorders, and infectious diseases.

Not all seafood-borne illnesses result from marine pollution. For example, disease outbreaks associated with fish include ciguatera, scombroid poisoning, and botulism (NRC, 1985). Ciguatera and scombroid poisoning were the first and second most frequently reported diseases associated with eating fish in the United States between 1977 and 1981 (Bryan, 1980; CDC, 1981; 1983). Ciguatoxin is a naturally occurring substance manufactured by certain dinoflagellate species (Bagnis et al., 1980) and transferred to fish through the food chain (Brown and Dorn, 1977). Scombroid poisoning results from eating fish which have become toxic as a result of microbial decomposition of histidine to histamine during improper handling and storage (NRC, 1985). Outbreaks associated with Clostridium botulinum are usually the result of faulty processing or storage practices.

Exposure to the biotoxins released from naturally occurring dinoflagellate species other than ciguatera represents a less frequent hazard to human health. Intensive blooms of dinoflagellates are known as red tides. The dinoflagellate Protogonyaulux tamarensis is responsible for producing paralytic shellfish poisoning (PSP) in exposed human populations along the New England Atlantic coast. Protogonyaulux cantenella is the organism responsible for cases of PSP on the Pacific coast (Steidinger, 1983). PSP, which has not been clearly linked to marine pollution, is one of the most toxic forms of food poisoning. Severe and often fatal human intoxications following ingestion of contaminated bivalve mollusks have occurred sporadically in widely scattered areas around the world (Ray, 1971). Statistically, PSP does not constitute a major public health concern in the United States, due in large part to successful state monitoring programs, although infrequent incidents have been reported along the Atlantic and Pacific coasts (CDC, 1983). Shellfish involved most frequently are mussels, clams (hard and soft-shelled), butter clams, and scallops (NRC, 1985). The dinoflagellate Ptychodiscus brevis is responsible for producing neurotoxic shellfish poisoning (NSP) in consumers of shellfish taken along the seacoast of North Carolina, South Carolina, Florida, and Texas. While it can kill fish and some invertebrates, P. brevis toxins accumulate in oysters and clams without harming them (Steidinger, 1983). These toxins can produce acute neurological effects in humans if sufficient quantities of shellfish meats are consumed.

Several Vibrio species that pose risks to human health occur naturally in the marine environment. Endemic Vibrio species associated with contamination of shellfish include V. parahaemolyticus and V. vulnificus. Consumption of seafood contaminated with V. parahaemolyticus has been associated with outbreaks of gastroenteritis, while consumption of V. vulnificus-contaminated shellfish can result in primary septicemia (blood poisoning) in patients with liver disorders and in diabetic and immunocompromised individuals (Tacket et al., 1984; Blake, 1979; NRC, 1985).

The initial step in determining which pollutants in the marine environment are likely to cause an adverse effect is to examine the association between disease incidence and human exposure. The association between exposure to human pathogens, either through ingestion of contaminated seafood or by swimming in contaminated water, and the development of human illness has been established for some agents. This association has been perhaps best established for exposure to enteric pathogens such as viruses and bacteria. Diseases such as hepatitis, gastroenteritis, and cholera are known to be caused by water- and seafood-borne pathogens. These pathogens can enter the marine environment through such practices as the discharge of raw sewage or wastewater effluent from sewage treatment plants and the dumping of sewage sludge. Pathogens may also enter the marine environment from nonpoint sources, such as agricultural or stormwater runoff, or through the illegal practice of ocean disposal of infectious wastes.

Human health effects resulting from exposure to toxic chemicals in the marine environment are less well known than the effects resulting from exposure to pathogens. Human health effects of toxic chemicals may be elicited as acute or sublethal responses. For example, populations of Minamata and Niigata, Japan, developed acute neurological disorders after consuming methylmercury-contaminated seafood (D'Itri and D'Itri, 1977). Sublethal effects were reported by Fein et al. (1984) in newborns whose mothers consumed large amounts of PCB-contaminated fish.

Metals other than mercury, including lead, cadmium, and arsenic, pesticides, halogenated compounds (such as dioxins), and polycyclic aromatic hydrocarbons (such as benzopyrenes) are also present in the marine environment and have the potential to cause adverse human health effects. Although the effects of these compounds on different organ systems in man and/or animals are known, it is difficult to establish with certainty the degree of hazard posed by their presence in seafood. This is due to a lack of information on the exact levels present, exposure duration, and, in the case of metals, the form in which they exist (e.g., inorganic vs. organic, oxidation states).

Toxic compounds enter the marine environment from a variety of sources. For example, a major source of cadmium is the discharge of industrial and municipal wastewater into estuarine waters. Pesticides, in contrast, are introduced into the marine environment largely from nonpoint sources, such as agricultural or stormwater runoff. Although mercury can enter the aquatic environment from industrial discharges or surface runoff, natural sources of mercury contribute most significantly to the levels found in the open ocean (OTA, 1987).

Once an indication of the relative hazard posed by a marine pollutant has been established, the next step is to characterize the degree to which particular populations are exposed to that agent. This involves quantifying the levels of contaminants in seafood, identifying the populations exposed to the toxic agent, and estimating the duration and nature of human exposure.

GOALS OF THE NATIONAL PROGRAM

Existing analytical methodologies allow for the detection and quantification of chemical contaminants in seafood at very low levels. This increased analytical sensitivity permits the detection of some compounds in seafood or marine waters at the part per trillion (ppt) level or lower; however, these results need to be integrated with exposure and toxicity data to develop a meaningful characterization of the risk of consuming contaminated seafood or of swimming in contaminated water.

Identifying the populations likely to be exposed to marine pollutants, and estimating the duration and frequency of exposure require accurate seafood consumption data. However, the wide range of national seafood consumption values currently available to regulatory agencies is a recognized source of uncertainty in assessing the human health risks posed by marine pollutants. For consumption data to be useful, they should be based on measurements from regional surveys of high-risk subpopulations in areas where problems exist. They should also be specific to certain seafood species, such as previously underutilized varieties. Any characterization of the degree to which populations are exposed to contaminants through consumption of seafood requires knowledge of the source of the contaminated seafood. This section focuses on seafood harvested in U.S. waters. However, much of the seafood consumed in this country is imported, and assessments of the risk to human health from consuming these seafood species must take into account the contribution of imported products to U.S. seafood consumption.

An important goal of this section is to review the existing seafood consumption data and address the need for updating this information. In addition to the risks associated with exposure to marine pollutants via consumption of contaminated seafood, other means of exposure to marine pollutants, such as occupational handling of seafood and swimming in contaminated water, are also considered in this section. However, since the pollutants being discussed are not unique to the marine environment, other sources of exposure, such as nonseafood dietary components, drinking water, and the ambient atmosphere contribute to the total body burden of these compounds.

Several methods have recently been developed to assess the human health risks from exposure to marine pollutants (EPA, 1987b; Brown et al., 1988; Friberg, 1988). Risk assessment is an important tool for evaluating human health concerns. The procedure takes into account toxicity and exposure information to provide a scientific framework for making policy decisions and taking regulatory actions. While information on human toxic responses is particularly valuable, typically such data either do not exist or are inadequate. Because of these uncertainties, the risk assessment approach is based on a quantitative calculation of the probabilities of an adverse health effect resulting from human exposure to a toxic agent.

The toxicity and exposure information gained in these risk assessment analyses can be used to support a number of management options. These include identifying and ranking polluted marine areas, developing environmental criteria, closing shellfish beds or bathing beaches, and issuing public health advisories. The effectiveness of these management tools is largely a result of the degree to which the population perceives the risk to be significant and the ability of the regulating agencies to communicate the risks. One goal of this section is to examine the effectiveness of these management tools in protecting human health.

Finally, recognizing the unique exposure to marine pollutants that emergency response workers often encounter, the measures necessary to protect these workers from adverse health effects will be examined in this section.

Federal Role

This section discusses the Federal legislation, regulations, and programs that address the implications of marine pollution to human health. Additional discussions of Federal programs related to specific information needs are presented under the management questions that follow this review of the Federal role. More detailed information on the Federal programs and projects that address the issue of human health and marine pollution can be found in the National Marine Pollution Program, Summary of Federal Programs and Projects (NOAA, 1987).

Federal Legislation and Regulations

The U.S. Food and Drug Administration (FDA) is responsible for the safety of the nation's foods, including seafood. Under the authority of the Federal Food, Drug and Cosmetic Act (FFDCA), the FDA assures that regulated products are safe for use by consumers. The FFDCA authorizes the FDA to conduct assessments of the safety of ingredients in foods. The key element of the FFDCA, and the source of FDA's main tools for enforcement, is the prohibition of the "adulteration" of foods. The FDA, under Section 406 of the FFDCA, can prescribe the level of contaminant that, under Section 402, will render a food adulterated and, therefore, will initiate enforcement action based on scientific data. The establishment of action levels (informal judgments about the level of a food contaminant to which consumers may be safely exposed) or tolerances (regulations having the force of law) are the regulatory procedures employed by FDA (or EPA, in the case of pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act) to control environmental contaminants in food.

The Federal Water Pollution Control Act, also known as the Clean Water Act (CWA), contains a stated goal that, where obtainable, all waters of the United States should be returned to "fishable, swimmable" status. This is achieved through two basic goals: (1) to reach a level of water quality that "provides for the protection and propagation of fish, shellfish, and wildlife" and "for recreation in and on the water," and (2) to eliminate the discharge of pollutants into U.S. waters. The National Pollution Discharge Elimination System (NPDES) mandated under Section 401 of the Act regulates, through a permit system, the discharge of pollutants into waters. Section 304 of the CWA requires EPA to periodically update water quality criteria to reflect the latest scientific knowledge on the effects of the individual pollutants on public health and welfare, aquatic life, and recreation. Section 303 of the Act provides that water quality standards be developed for all surface waters. Section 311 prohibits the discharge of "harmful quantities" of oil into navigable waters. Section 403 of the Act requires EPA to establish criteria for the discharge of hazardous pollutants into the territorial sea, the waters of the contiguous zone, and the oceans. Approximately 300 substances have been designated by the EPA as hazardous. The EPA is responsible, under Section 405 of the Act, for regulating the disposal of sewage sludge by pipeline, and Section 301(h) provides EPA with the authority, under certain conditions, to issue permits waiving secondary treatment of sewage effluents from publicly owned treatment facilities discharging into marine waters. Section 208 of the CWA calls for state agencies to develop and implement nonpoint source pollution control and management plans, with EPA approval and limited oversight.

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The Marine Protection, Research and Sanctuaries Act (MPRSA) provides for the regulation of ocean dumping. Title I of the Act identifies EPA as being responsible for issuing permits for the ocean dumping of any material (except dredged material). Ocean dumping permit reviews are based on several criteria including the economic, aesthetic, and recreational effects of such dumping on public health and welfare. Title II establishes a comprehensive monitoring and research program on the effects of ocean dumping and long-term effects of pollution, overfishing, and man-induced changes to the marine environment. This long-term program includes monitoring programs to assess the health of the marine environment.

The EPA specifically regulates toxic substances that may enter the marine environment, and thus affect human health, with four mandates. The Toxic Substances Control Act (TSCA) assigns to EPA the responsibility for regulating hazardous chemical substances and mixtures in Section 6 of the Act. Section 10 of TSCA identifies EPA as the agency responsible for obtaining adequate data on health and environmental implications of potentially toxic substances. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA has the responsibility for pesticide registration and classification based on health hazards and environmental effects. FIFRA also requires EPA to conduct research and monitoring programs to assist in the control and use of pesticides and to expand protection of the public health and the environment. The Resource Conservation and Recovery Act (RCRA) requires EPA to promulgate regulations establishing standards for transportation of hazardous waste, and for ownership and operation of hazardous waste treatment, storage, and disposal facilities. The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) provides Federal funding to respond to the release of hazardous substances into the air, land, or water. Under CERCLA, the National Contingency Plan (NCP), which provides a method for ranking waste sites for inventory and cleanup, also contains oil spill response provisions in conjunction with the CWA.

The Fish and Wildlife Act (FWA) contains a congressional declaration of policy to the effect that fish and wildlife resources make a material contribution to the national economy and food supply. Among other things, the Act transferred to the Secretary of Interior, and subsequently to the Department of Commerce, certain functions previously assigned to the Secretary of Agriculture pertaining to seafoods. In addition to the transfers of functions with respect to fishery products, Section 741 of the Act identifies a need for government assistance to industry in promoting fair trade standards and health and sanitation standards.

Federal Programs

Although this is the first Federal Plan for Ocean Pollution Research, Development, and Monitoring to include a separate section on the human health effects of marine pollution, previous Federal Plans have addressed research activities pertaining to human health as a high priority. However, since this is the first Plan to review human health effects research separately, it is difficult to provide an assessment of the Federal level of effort for research and monitoring projects related to the human health effects of marine pollutants. This is due to the fact that much human health effects research is conducted outside the bounds of the National Marine Pollution Program. Nevertheless, several Federal programs have been identified that relate generally to human health effects from marine pollution.

The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, the Food and Drug Administration (FDA) and National Institute of Environmental Health Sciences (NIEHS) of the U.S. Department of Health and Human Services (DHHS), and the U.S. Environmental Protection Agency (EPA) are major supporters of research concerning the implications of marine pollution to human health. The U.S. Coast Guard also conducts activities related to this issue.

NOAA's human health-related activities are conducted by the National Marine Fisheries Service (NMFS), the National Ocean Service (NOS), and the Office of Oceanic and Atmospheric Research (OAR). The NMFS's related research is designed to evaluate the public health significance of contaminants occurring in finfish and shellfish. The agency conducts studies of the levels of various contaminants (PCBs, pathogens, petroleum hydrocarbon residues, and others) in fish and shellfish, develops methods for extracting and assaying contaminants in marine tissues, evaluates the potential use of improved indicators of fecal contamination, and evaluates the effectiveness of depuration in eliminating bacterial and viral contaminants in shellfish. The NMFS's Model Seafood Surveillance Program was created to design a program of certification and surveillance to improve the inspection of seafood by focusing on the monitoring of necessary critical control points in food operations. The NMFS also transfers new technology and information to state and Federal public health agencies. The NOS activities include research to identify accurate indicators of disease risk to consumers of raw shellfish and to isolate the organism responsible for causing diarrhetic shellfish poisoning in shellfish to determine its optimum growth conditions. Through its National Status and Trends Program's Benthic Surveillance Project, NOS collects bottom-feeding fishes in selected areas and analyzes their livers for toxic metals, organic chemicals, and metabolites of aromatic hydrocarbons. The National Status and Trends Program also monitors contaminants in some molluscan shellfish. Through its Quality of Shellfish-Growing Waters Project, the NOS conducts assessments of the trends in classification of shellfish-growing waters in selected estuaries and identifies the pollutants affecting these waters. The NOS is also comparing the utility of various chemical tracers of sewage. The NMFS and NOS (in cooperation with FDA, EPA, and the U.S. Fish and Wildlife Service) have developed the National Shellfish Register, an inventory of the status of shellfish-growing waters as classified by state shellfish sanitation control agencies. The NOS, in conjunction with the U.S. Coast Guard, has developed CAMEO (Computer-Aided Management of Emergency Operations), a microcomputer-based system intended for use in accidental coastal oil spills, chemical spills, and other emergency response activities. The Hazardous Materials (HAZMAT) Response Branch has used CAMEO to analyze spill situations, determine effective counter measures, and estimate the scope of potential down-wind hazard zones. Within OAR, the Sea Grant Program funds studies to determine the depuration of shellfish contaminated with environmental pollutants and the persistence of chemical contaminant residues in fish tissue; identifies the origin of fecal coliforms in coastal waters; and assesses the potential hazards of diving in polluted waters. The Sea Grant Program and NMFS fund research related to the development of methods to permit rapid identification of pathogens and to identify new representative indicators of fecal coliform in the marine environment.

The FDA develops methods for detecting, quantifying, and identifying contaminants in shellfish and estuarine waters. The FDA also supports the National Shellfish Sanitation Program (NSSP), a cooperative state/Federal/industry program for the sanitary control of the shellfish industry. As part of the NSSP, FDA provides technical assistance to states in studying specific pollution problems; provides data to establish closure levels for shellfish harvesting; conducts applied research on various contaminants to assist in developing standards and criteria; and evaluates the effectiveness of state shellfish sanitary control programs. The

NIEHS supports five Marine and Freshwater Biomedical Science Centers, which assess the use of aquatic species as models for studying mechanisms of toxicity with relevance to humans. The agency also uses aquatic species in studies of metabolic fate and distribution of contaminants in tissues.

The EPA is funding a joint project with Great Lakes states and the FDA to determine the potential human exposure to contaminants from Great Lakes seafood. The agency is also conducting research in collaboration with the National Cancer Institute to study environmental cancer through the use of aquatic species as models for identifying environmental problems and providing better understanding of the risks associated with exposure to environmental carcinogens. In addition, EPA is producing data and information on the relative efficacy of fish species as carcinogen/teratogen assay subjects in comparison to present mammalian test species.

The U.S. Coast Guard's related activities include the identification and characterization of operational requirements for hazardous chemical response personnel/marine inspectors and the development of hazardous chemical protective ensembles, including totally encapsulated suits to protect against a full range of chemicals.

These Federal agency programs relate only to those activities directly involved in investigating the human health effects of marine pollutants, or in protecting public health by limiting exposure to these toxic agents. Since most of the marine pollutants of concern are not unique to the marine environment, the toxic or human health effects of these substances are broadly addressed in a number of other Federal agency programs that do not deal specifically with marine-related activities. Therefore, Federal agencies are involved in addressing these concerns to a greater degree than may be represented by this discussion of programs. For example, toxicity testing and human health effects research are conducted by a wide range of Federal agencies, institutes, and programs including the National Toxicology Program, the Agency for Toxic Substances and Disease Registry, the National Cancer Institute, and others. The research programs conducted or sponsored by these groups address questions fundamental to determining the toxicity of marine pollutants and the mechanisms by which these agents act. Several of these research efforts will be explored in greater detail in the discussions pertaining to each management question.

Management Questions and Information Needs

An understanding of the adverse human health effects that may result from exposure to contaminants in the marine environment is important for managing these problems. Listed below are four management questions that need to be addressed to achieve this goal.

Management Question 1: What are the human health concerns associated with exposure to chemical contaminants in the marine environment?

Management Question 2: What are the human health concerns associated with pathogenic microorganisms in the marine environment?

Management Question 3: Have management tools been effective in protecting human health?

Management Question 4: What are the human health concerns associated with spills of hazardous materials in the marine environment?

This section will include a discussion of the rationale, current efforts, and information needs remaining for each management question.

Concerns Associated with Chemical Contaminants

<u>Management Question 1: What are the human health concerns associated with exposure to chemical contaminants in the marine environment</u>?

Information Needs

1a. What concentrations of potentially toxic chemical substances are occurring in important commercial and recreational species?

1b. What are the seafood consumption patterns in the United States?

1c. Does the interaction of mixtures of toxic chemicals pose significant added risks to human health?

1d. What risks result from exposure of seafood handlers to seafood raw material?

1e. What risks result from direct exposure(s) to chemical contaminants in the marine environment?

<u>1a. What concentrations of potentially toxic chemical substances are occurring in important commercial and recreational species</u>?

Various pollutants are discharged into U.S. waters in large quantities. Among these are metals and organic chemicals. However, only a limited number and variety of aquatic species and chemical pollutants are routinely monitored. Coastal states monitor contaminant levels in seafood to assist in determining when and where advisories should be issued against the consumption by humans of certain types of seafood. State monitoring data for selected species and contaminants are presented in Table 7. These data were selected to illustrate possible problem situations with respect to human health for a variety of species, contaminants, and regions, and are not intended to be representative of conditions in estuaries around the United States. State monitoring programs do not use consistent methods for sample collection and preparation and chemical analysis, thereby limiting the ability to make comparisons.

It would be impractical and financially prohibitive to sample all fish and shellfish for chemical contaminants. Therefore, one must select appropriate target species and contaminants of concern. To provide guidance, the FDA has developed sampling designs for the collection of seafood products from the marketplace (FDA, 1986). One approach would be to determine the species that represented the greatest percentage of the catch of commercial and recreational fishermen and analyze the edible tissues of those species. In the past, this approach has been taken for the NOAA survey of marine fish in Puget Sound (Malins et al., 1980) and the New York Bight (MacLeod et al., 1981), as well as the FDA Market Basket survey. Alternatively, one could select an indicator species that is thought to represent a special concern due to the ability of that species to bioaccumulate potentially toxic

Table 7. Concentrations of Organic Chemicals in Selected Fish Species (from NOAA, In Preparation)*

Chemical Contaminant	Fish	Tissue Type	Location	Average Tissue Level (ppm)	FDA Action Level (ppm)
Chlordane	gizzard shad	whole fish	Chesapeake Bay and Tributaries, MD	0.6[a]	0.3
DDT	white croaker	fillet	Palos Verdes Peninsula, CA	7.6[b]	5.0
HCB	sea trout	edible composite	Bayou D'Inde, Gulf Coast, LA	0.11[c]	Not established
Naphthalene (PAH)	bottom fish	fillet	Puget Sound, WA	0.5[d]	Not established
PCB	striped bass	composite	Lower Hudson River, NY	4.0[e]	2.0
PCB	striped bass	fillet	Narragansett Bay	4.0[f]	2.0

[a]Maryland Department of the Environment, 1987.
[b]California Department of Health Services, 1988.
[c]Louisiana Department of Environmental Quality, 1987.
[d]Puget Sound Fish Catch & Consumption Survey, 1984.
[e]New York State Department of Environmental Conservation, Fish and Wildlife Health Advice, 1987.
[f]Rhode Island Department of Health, 1987.

*These data were selected to illustrate the potential for human health effects and may not be representative of contaminants in other species or sample sites or at other times.

substances, or due to a higher rate of consumption of this species by individuals in a specific geographical area. This was the approach taken by NOAA (1986), in conjunction with the FDA and EPA, in their extensive survey of PCBs in Atlantic coast bluefish.

NOAA's National Marine Fisheries Service has an ongoing program to determine the kinds and levels of contaminants in the tissues of fishery products of recreational, food, and industrial use. The program focuses on the ultimate impact of chemical contaminants and pathogens in the marine environment on human health. Three types of information are evaluated in an attempt to accurately determine the public health significance of contaminants in fish. They are: (1) the identification and measurement of contaminants of public health significance in fish and shellfish; (2) determination of the chemical form and potential for interactions among the contaminants; and (3) evaluation of consumption patterns for fishery products in the United States. Information generated by the program is used by various agencies and groups responsible for consumer safety, resource management decisions, and the harvesting and utilization of national marine resources.

Current Federal monitoring programs include the NOAA National Status and Trends (NS&T) Program and EPA's Mussel Watch Program. Although the NS&T Program is not concerned directly with human health, two program elements (the Benthic Surveillance Project and the Mussel Watch Project) provide useful data regarding contaminant levels of environmental pollutants. NOAA's Mussel Watch Project includes annual sampling of mussels and oysters from 150 coastal and estuarine sites along the U.S. Atlantic, Gulf, and Pacific coastlines. Organisms and sediments have been analyzed for selected PAHs, synthetic chlorinated compounds, PCB congeners, and trace metals.

The Food and Drug Administration (FDA) has estimated the exposure of U.S. citizens to chemical contaminants in their food through Total Diet Studies (also known as the Market Basket Program) since the early 1960's for adults, and since 1974 for infants and toddlers (Gartrell et al., 1986). In these studies, samples representing the annual average diet are analyzed for selected pesticides and industrial chemicals. The Total Diet Studies include a seafood component. Overall, however, relatively little of the fish caught and sold in this country is screened for chemical contaminants. A study by Capuzzo et al. (1987) reports that FDA tested less than 0.001 percent of the fish consumed in the United States in 1982 for chemical contaminants.

Although most of our seafood is safe for human consumption, available information on chemical contaminant concentrations in marine species suggests that risks to human health could result from consumption of fish and shellfish from U.S. coastal waters. These risks would occur at different levels for different areas, species, and contaminants. Surveillance activity for the assessment of microconstituents in seafood in this country is piecemeal and unorganized at best. It occurs at Federal, state, and local levels, but the extent of activity at each of these levels varies tremendously. At the Federal level, the ability of the FDA and NMFS to conduct this type of work is limited. This is due to limitations in available resources that can be committed to this activity. These limitations include the lack of scientific and compliance personnel, equipment, and up-to-date surveys of seafood consumption and microconstituent levels in seafood. Improved routine monitoring of contaminant concentrations in commercial and recreational species will be needed before human health risks associated with consumption of seafood can be assessed effectively.

Programs for monitoring concentrations of contaminants in seafood could be improved in the following ways:

- *Intensify monitoring. Existing Federal and state programs provide limited data on the concentrations of chemical contaminants in edible tissues of commercial and recreational fish species. Frequency of sampling is too limited on both temporal and spatial scales. Existing Federal programs such as the NS&T Program are not designed to manage human health risks and, although they serve other important needs, do not provide sufficient information for protecting human health.*

- *Standardize methods. Sampling and analysis protocols should be established by the Federal Government as to critical factors such as which tissues to assay, specimen size (or age) class, sex and reproductive condition, sampling season, number of replicates, and methods of chemical analysis (EPA, 1987b). Standard protocols are especially important because much of this monitoring is conducted individually by the states.*

1b. What are the seafood consumption patterns in the United States?

Data on seafood consumption patterns in the United States are available on an average basis for the U.S. population. Standard values for seafood consumption rates have usually been based on previous analyses of dietary patterns of the U.S. population (EPA, 1980; SRI, 1980). The NMFS seafood consumption study of 1973-1974 reported that the average U.S. per capita daily consumption of seafood was 18.7 grams, which could be subdivided into 6.5 grams of estuarine fish and shellfish, 2.0 grams of freshwater fish, 2.8 grams of marine fish, and the remaining 7.4 grams being primarily tuna and some unclassified imported fish.

The United States Department of Agriculture (USDA) accumulates fish consumption data by surveying customers and by collecting market data. The USDA Nationwide Food Consumption Surveys for individuals reported average fish consumption rates of 12 grams per day in 1977-1978 and 5, 11, and 21 grams per day in 1985 for children, women, and men, respectively. The USDA agricultural market survey data indicate a per capita intake of all fish (marine and freshwater) in 1983 of 18.4 grams per day, similar to that estimated by NMFS market data for per capita fish and shellfish consumption in 1986.

A figure of 6.5 grams per day for consumption of commercially and recreationally harvested fish and shellfish from estuarine and fresh waters was used by EPA (1980) to develop water quality criteria based on human health guidelines. This value is an average per capita consumption rate for the U.S. population based on the data of SRI (1980).

The EPA Office of Pesticide Programs (OPP) has examined the various surveys and market data available and concluded that the 1977-1978 USDA Nationwide Food Consumption Survey is the most reliable database for this information, based on sample size and data collection methods. Data from this survey were employed to develop the EPA Tolerance Assessment System (TAS), which breaks down seafood consumption data by age group for the U.S. population.

Data available on fish and shellfish consumption in the United States are neither comprehensive nor current. The question of consumption rates in certain geographic or cultural subpopulations is a major source of uncertainty. Average daily seafood consumption rates do not adequately describe the dietary patterns of certain sectors of the U.S. population. For example, Finch (1973) estimated that 0.1% of the U.S. population consumes 165 grams per day of commercially harvested fish and shellfish. More recently, Pao et al. (1982), estimated that 5% of the U.S. population consumes in excess of 128 grams per day of fish and shellfish. High rates of consumption tend to be correlated with geographic and cultural patterns. Thus, Humphrey (1976) reported that Great Lakes sport fishermen consumed an average of 31 grams per day of fish from Lake Michigan alone; one individual was reported to consume 10 times this amount. In another example of very high fish consumption, Marsh et al. (1974) described a group of fishermen in American Samoa that consumed up to 250 grams of fish per day.

Current and more specific information (e.g., surveys) on the consumption of fish and shellfish in this country, including quantitative intake, species, geographic origin, and methods of preparation would greatly improve our ability to estimate risks to human health associated with consumption of seafood. The consumption data presently in use were collected at least a decade ago and their applicability to estimating the current consumption of seafood in this country is questionable. Methodologies for collecting data on fish consumption, as well as approaches for using limited data to estimate intake, should be improved. The surveys should include information on seafood consumption, not only on a national level, but also on a *regional level because the consumption of seafood is determined to a great extent by regional factors (e.g., availability and access to fishery resources). These surveys should collect information on high-risk sectors of the population, as well as the average consumption in each region.*

1c. Does the interaction of mixtures of toxic chemicals pose significant added risks to human health?

Humans are rarely exposed to single chemicals in the marine environment. Direct and indirect exposures to naturally occurring and synthetic materials are often to mixtures of chemicals from a variety of sources. Until very recently, tests designed to detect adverse health effects as a result of exposure to chemical mixtures have been rudimentary in nature. Such tests have reflected insensitive analytical methods and the inherent complexities in testing chemical mixtures, lack of adequate toxicity information on individual compounds and mixtures, and difficulties in satisfactory interpretations of the results. Consequently, limited information is now available to evaluate health effects associated with exposure to mixtures of chemicals in the marine environment.

Environmental transport, mobility, and distribution are important processes in understanding the toxicity of both individual pollutants and mixtures of chemicals. Physicochemical characteristics such as water solubility, lipid solubility, partitioning behavior, vapor pressure, and chemical stability are critical properties that can significantly influence the behavior of a chemical in a system and impact the nature and degree of a toxic endpoint. Transformations of environmental pollutants may occur via chemical, biological, geological, and physical (e.g., photolysis) reactions. Transport and circulation, adsorption to suspended-sediment particles, degradation by soil microorganisms, and deposition in ultimate sinks such as deep ocean sediments illustrate a complex chain of processes undergone by chemicals and mixtures of chemicals when they are released in the environment. These environmental processes may change parent compounds into more toxic, less toxic, or nontoxic species before chemical interactions occur. These topics are addressed in greater detail in the toxic materials section of this chapter.

Early studies often failed to account for potentially significant chemical interactions taking place between individual constituents in a chemical mixture. Although the toxicity of a mixture has sometimes been approximated by adding the toxicities of the individual constituents (assuming they can be identified and there are toxicity data available), significant interactions such as synergism, additivity, or antagonism can occur. These interactions may preclude the accurate determination of the carcinogenic potency, acute lethality, or chronic toxicity of a mixture by simply adding the toxicities of the constituents.

Synergistic interactions between chemicals at high doses are known to produce effects that are greater than the additive effects of the individual chemicals. Uncertainty still exists concerning the significance of interactions at low doses of chemical mixtures, such as those typically found in contaminated seafood. Investigators are using new technologies to address the problems of testing and characterizing complex mixtures of environmental pollutants (both toxicologically and chemically) (Fouts, 1988; McKinney, 1988; Safe, 1988; Vanderslice et al., 1988; Albert et al., 1983). Safe (1988) has focused on the development and validation of in vitro enzyme assays in rat cells for quantifying individual toxic halogenated aryl hydrocarbons and their mixtures. Albert et al. (1983) and Lewtas (1985) used a method known as relative (comparative) potency to evaluate risks to human health caused by chemical mixtures. This approach is based on the assumption that for similar but not necessarily definable complex mixtures, a measure of relative potency based on data from in vitro tests can be correlated in a constant fashion with relative potency from an in vivo bioassay.

Research on chemical mixtures has been conducted by several Federal agencies. A workshop assembled by the Environmental Protection Agency (EPA, 1984) developed early approaches for risk assessment methods of multiple chemical exposures. Principles developed by this group were incorporated into the EPA Guidelines for the Health Risk Assessment of Chemical Mixtures (EPA, 1986b). The National Academy of Sciences (NAS) has recently issued a publication that addresses the toxicity and adverse health effects of complex chemical mixtures (NAS, 1987). In addition to the NAS, the World Health Organization (WHO) has also recently published information on adverse health effects associated with chemical mixtures.

The National Toxicology Program (NTP) and the NIEHS are also actively investigating how mixtures of compounds found in the marine environment may adversely affect human health. The NTP has initiated an empirical study of the toxicity of well-defined chemical mixtures to rodents (Yung and Rauckman, 1987); additional parameters to be investigated are the frequency of synergism or antagonism, and development of mechanistic approaches for studying chemical interactions. To gain insights into the potential for toxicity to humans of chemical mixtures via dietary exposures, the NIEHS will sponsor a conference in the fall of 1988. Specifically, the meeting will address the question of whether the consumption of aquatic food organisms may convey carcinogens to human consumers in amounts or forms sufficient to increase their cancer risk.

Despite such progress, the EPA concluded that it is still very difficult to predict synergistic or antagonistic effects of most chemical mixtures (EPA, 1987b). The approach used most frequently for multichemical risk assessments is the additive risk model (also known as the response-additive model) (EPA, 1987b). Numerical estimates obtained using this model have been useful in terms of relative comparisons (e.g., among fishing areas or among fishery species). However, current risk estimates for chemical mixtures should be regarded only as rough measures of actual risk.

The current state of the art in mixture toxicology does not allow us to accurately predict the interactive effects of chemical mixtures that may result from the consumption of contaminated seafood (EPA, 1986a). Due to limitations in availability of data and in the ethodology to assess these risks, disagreement exists as to the significance of exposure to chemical mixtures in evaluating human health risks. To resolve these disagreements, advances would be needed in at least the following areas:

- *Improved ability to determine concentrations of toxic substances in mixtures;*
- *More complete understanding of the toxicity to humans of individual substances; and*
- *Understanding of the effects of interactions among groups of toxic substances and how these interactions influence toxic response.*

Although progress will be difficult, it is recommended that research be continued on understanding toxicity of mixtures along with other basic toxicological questions.

1d. What risks result from exposure of seafood handlers to seafood raw material?

Although workers in the canned and cured seafood industries are among those with the highest incidence of occupational skin disease, these problems appear to be the result of bacterial infections of abrasions and cuts caused by spines, fins, and bones of fish and are not the result of handling chemically contaminated seafood. In addition, results of two epidemiological studies of seafood handlers suggest that the development of many adverse health effects in this population originate from exposure to water, noise, cold, dampness, or to ergonomic factors leading to musculoskeletal stress and discomfort (NIOSH, 1986).

No evidence exists to indicate that occupational exposure to chemically contaminated seafood is a health concern. Therefore, no high-priority research needs have been identified in this area.

1e. What risks result from direct exposure(s) to chemical contaminants in the marine environment?

Direct human exposure to toxic compounds in the marine environment could also occur through swimming or diving in polluted waters. Little information, however, exists on the adverse health effects that result from this route of exposure. The New Jersey Department of Environmental Protection (NJDEP) has initiated one of the few studies concerning the public health effects of direct discharges of pollutants into the ocean. This study focused on a pharmaceutical firm in New Jersey that has discharged treated wastewater into the Atlantic Ocean since 1966. As of 1987, this plant was discharging 4 to 5 million gallons of wastewater per day into the ocean from a pipe that extends 3,500 feet out to sea from the shoreline. From their initial studies, NJDEP concluded that the discharge from this plant did not pose a measurable health risk to persons swimming on the nearby beaches (EPA, 1987a).

Existing information indicates that exposure to chemical contaminants during swimming and diving do not pose a serious or widespread threat to human health. Although little attention has been paid to examining the risks associated with exposure to toxic chemicals at marine bathing beaches or to the joint effects of pathogens and chemicals on swimmers, no high-priority research needs have been identified in this area.

Concerns Associated with Pathogens

Management Question 2: What are the human health concerns associated with pathogenic microorganisms in the marine environment?

Information Needs

2a. What microorganisms in the marine environment are currently causing adverse human health effects?

2b. How effective are traditional indicators at predicting actual risks associated with exposure to microorganisms?

2c. What human activities contribute most significantly to the numbers of human pathogens entering the marine environment?

2d. Are present disinfection techniques adequate for controlling the introduction of pathogens into the marine environment?

2a. What microorganisms in the marine environment are currently causing adverse human health effects?

Human pathogens found in the marine environment include viruses, bacteria, protozoa, and fungi. Surface runoff and sanitary wastes discharged directly or indirectly (via rivers) into the marine environment may contain microorganisms that are capable of causing adverse human health effects. Other microorganisms capable of causing human diseases occur naturally in the marine environment and are not a result of polluting activities. In the United States, viruses and bacteria are the most important human pathogens, both in terms of the number of organisms released to the environment and in the severity of the diseases they cause (OTA, 1987). People can be exposed to pathogens either directly from ocean water or indirectly through ingestion of contaminated seafood. Both pathways may be significant since as few as 10 to 100 bacteria are capable of inducing disease under the appropriate conditions (OTA, 1987); additionally, many pathogens can reproduce in wastes, contaminated media, and infected organisms.

Closures of shellfishing grounds because of contamination with sewage-derived microorganisms have largely eliminated outbreaks of serious shellfish-borne, bacterial diseases in the United States, including epidemics of typhoid and cholera. In addition, control technologies being used in this country have been or should be adequate for reducing the risk of water-related, pollution-associated bacterial diseases to an acceptable level. However, questions remain as to the effectiveness of control techniques in limiting water-borne viral disease.

Table 8 provides examples of pathogenic organisms known to cause adverse human health effects. In many cases, additional information regarding the ecology, epidemiology, and pathogenicity of these species is needed to more fully confirm their association with causes of human illness.

Viral agents, notably the Norwalk-like viruses and hepatitis A, contained in raw or partially cooked molluscan shellfish that have been harvested or held in waters polluted with sewage may cause illness in humans. The Norwalk-like viruses have been increasingly shown to be the etiological agents responsible for acute gastroenteritis outbreaks that have resulted from consumption of contaminated seafood and swimming in contaminated waters (Kaplan et al., 1982). Since 1970, several reports have linked hepatitis A to consumption of raw or partially cooked molluscan shellfish (Feingold, 1973; CDC, 1979b; 1982; Guidon and Pierach, 1973; Ohara et al., 1983).

Sewage-derived bacterial agents associated with contaminated molluscan shellfish can also cause human illness. However, these agents, which include the bacteria responsible for typhoid and cholera, are adequately controlled using existing sewage treatment and shellfish management techniques and do not appear to be a serious human health problem at this time.

Research is being conducted by NOAA investigators to detect and quantify pathogens in marine water and shellfish. These projects include a study by the NOAA/NMFS Charleston Laboratory to develop and evaluate methods for extracting and assaying enteric viruses such as hepatitis A virus and Norwalk virus from molluscan shellfish. NOAA-sponsored research is

Table 8. Microorganisms Responsible for Causing Adverse Human Health Effects*

Disease	Pathogenic Organism	Seafood Source	Reference
Hepatitis	Hepatitis A virus	Raw oysters	Roos (1956)
		Steamed clams	Bryan and Huff (1973)
		Steamed and raw clams	Feingold (1973)
		Raw clams	CDC (1982)
		Raw oysters	Ohara et al. (1983)
		Oysters	Portnoy et al. (1975)
		Cockles	O'Mahony et al. (1983)
		Raw molluscan Shellfish	Koff et al. (1967)
	Non-A and non-B hepatitis virus	Raw molluscan Shellfish	Alter et al. (1982)
Gastroenteritis	*Aeromonas hydrophilia and Plesiomonas shigelloides*	Shellfish	Holmberg and Farmer (1984)
	Vibrio mimicus	Raw oysters	Shandera et al. (1983)
	Vibrio parahaemolyticus	Clams and snails	Roland (1979)
		Raw oysters	Nolan et al. (1984)
		Crab	Dadisman et al. (1973)
		Shrimp	Baker et al. (1974)
		Lobster	Baker (1974)
	Vibrio vulnificus	Raw oysters	Brady and Concannon (1984)
			Pollak et al. (1983)
	Vibrio cholera 0 group	Raw oysters boiled shrimp, boiled crab	CDC (1980)
	Vibrio cholera Non-0 group 1	Raw oysters	Wilson et al. (1981)
			Morris et al. (1981)
			CDC (1979a)
	Norwalk virus	Raw oysters	Linco and Grohmann (1980)
			Murphy et al. (1979)
			Guinn et al. (1982)
		Raw clams	CDC (1982)
	Small round structured virus	Raw oysters	Gill et al. (1983)
	Campylobacter jejuni	Raw clams	Griffin et al. (1983)

* Includes naturally occurring microorganisms as well as microorganisms associated with pollution.

being conducted at the Baylor College of Medicine to evaluate the merits of a new A-ELISA test for detection of hepatitis A virus in the estuarine environment and to determine the extent of hepatitis and rotavirus occurrence in polluted waters. A serological test for identification of species of Vibrio is under development by the Louisiana Sea Grant College Program. At the University of Maryland, an epidemiological study of the microbiological hazards associated with diving in polluted waters is currently being conducted. These researchers are also studying the feasibility of adapting rapid serological techniques for use in a field hazards test kit for divers.

In addition to sponsoring research activities in this area, the Federal Government is also involved in several inspection programs designed to protect the population from the hazards of consuming pathogen-contaminated seafood. The National Marine Fisheries Service (NMFS) conducts inspections of fish and shellfish to check for "wholesomeness," safety, and labeling. Participation by the seafood industry in this program is voluntary, and inspections are provided at the request of the processor. Another voluntary inspection program, the National Shellfish Sanitation Program (NSSP) has been established as a joint effort between the FDA, state agencies, and the shellfish industry to set forth guidelines for the management of state shellfish programs. Under this program, the FDA has the primary responsibility for the development of the NSSP Manual of Operations to be used by individual states. These guidelines contain the criteria and standards for the sanitation of shellfish-growing areas and the sanitation of the harvesting and processing of shellfish. In 1982, the Interstate Shellfish Sanitation Conference (ISSC) was formed to strengthen the NSSP. Two years later, FDA entered into a Memorandum of Understanding with the ISSC and reaffirmed the voluntary cooperative relationship with both the states and the shellfish industry. The purpose of the ISSC is to provide a formal structure wherein regulatory authorities could establish updated guidelines and procedures for the uniform control of shellfish sanitation guidelines.

As discussed above, some human health problems associated with the ingestion of seafood are not linked to marine pollution. However, a number of microorganisms, particularly viruses, that are associated with marine pollution have been shown to cause various human diseases such as hepatitis and gastroenteritis, primarily when molluscan products are eaten raw, partially cooked, mishandled, or misprepared. It is difficult to estimate the frequency with which marine pollution causes human disease in the United States. Many cases go unreported. Research in this area should be continued to improve our understanding of which pollution-related pathogens are causing human health problems and to improve our ability to screen and monitor seafood and water quality for human pathogens.

2b. How effective are traditional indicators at predicting actual risks associated with exposure to microorganisms?

Concentrations of coliform bacteria, expressed as Most Probable Number (MPN) per 100 milliliters, have been employed for decades as a component of microbiological standards to monitor the quality of waters for swimming and shellfish harvesting (OTA, 1987; DHEW, 1965). Although currently used microbial indicators have been effective in protecting the U.S. population from shellfish-mediated epidemics, existing water quality standards have been questioned as true indicators of the overall potential for human disease. The indicators and standards have not been related to disease through epidemiological studies, and although indicators used reflect the presence of fecal wastes, they are not specific to humans, nor to two common causes of disease: viral pathogens and free-living, opportunistic pathogens such as

V. vulnificus (Ronk, 1988). This problem is exemplified by instances of the ingestion of molluscan shellfish harvested from waters classified as acceptable by the traditional indicators that have resulted in sporadic outbreaks of viral disease (Portnoy et al., 1975).

Fecal coliform bacteria are also thought to be inadequate for predicting the risks associated with direct exposures to pathogens in the marine environment. In a study of New York beaches, Cabelli et al. (1979) presented evidence that there are measurable health effects associated with swimming in sewage-polluted waters, and that, in some cases, these effects were observed even in waters that were in compliance with existing recreational water quality guidelines and standards. Cabelli et al. (1982) expanded these studies to additional beaches in Louisiana and Massachusetts. Of the indicators quantified, the density of enterococci was highly correlated with the incidence of gastrointestinal symptoms (GI) among swimmers at both locations. Additionally, they reported that swimming-associated GI symptoms were poorly correlated with fecal coliform densities, the indicator used most in Federal and state standards.

Fecal coliforms generally are not pathogenic, and do not survive as well in the marine environment compared to at least one type of bacterial pathogen (Rhodes and Kator, 1983). Although existing standards employ bacteria as indicators of contamination, viruses are being recognized as major etiologic agents for swimming- or seafood consumption-associated disease. Morse et al. (1986) reported the role of the Norwalk virus in outbreaks of shellfish-associated gastroenteritis. Previous studies (Gerba et al., 1979; Portnoy et al., 1975) have illustrated the failure of bacterial indicators to demonstrate the presence of enteroviruses in marine waters.

Some bacteria (including certain human pathogens) in the marine environment may remain in a dormant state and retain their viability for extended periods of time (e.g., months to years). For example, Vibrio cholerae (Colwell et al., 1985), Campylobacter jejuni (Rollins and Colwell, 1986), and Salmonella enteritidis (Roszak et al., 1984) may exist in such a viable but nonculturable state in the marine environment. In the dormant state, the presence of these organisms cannot be detected using standard microbial assays. However, these pathogens may be "reactivated" within a suitable host organism (Colwell et al., 1985). Thus, the apparent lack of human pathogens in the open ocean and near-shore coastal waters may simply reflect an inability to detect these apparently viable, but nonculturable microorganisms (Grimes, 1986). Recently developed monoclonal antibody and gene probe techniques permit the detection and quantification of both culturable and nonculturable microorganisms. Since these methods have the ability to detect nonculturable organisms, they may serve as more precise techniques for monitoring microbiological water quality.

The Federal Government has addressed some of the inadequacies of current microbiological standards for water quality, and has initiated research programs and regulatory actions. Based largely on the work of Cabelli and others (Cabelli et al., 1979; 1982; Miescier and Cabelli, 1982), the EPA has adopted enterococci as an indicator of microbiological water quality for recreational marine waters. Since 1985, NOAA and EPA have collaborated on an epidemiological investigation to study the health effects associated with shellfish consumption. The association between gastrointestinal illness in individuals who eat raw shellfish and the quality of shellfish-harvesting waters is being examined in this study. Also, a clinical feeding trial is currently being conducted in which the health of volunteers is monitored after eating raw oysters harvested from either an area that is affected by treated sewage effluent but still meets the current standard for shellfish-harvesting waters (Dufour, 1987). Additionally, the

National Collaborative Shellfish Pollution Indicator Study has been proposed as a four year effort to evaluate the current relationship between indicators of human enteric pathogens and the incidence of shellfish-borne disease.

Traditional indicators of microbial contaminants appear to be inadequate for predicting human health risks associated with both consuming molluscan shellfish and swimming in waters that contain sewage-associated viruses, naturally occurring bacteria, and, occasionally, sewage-associated bacteria. The need exists to identify microbial indicators specific for human fecal wastes that survive wastewater treatment, disinfection, and residence in marine waters and that are effective in predicting the presence of viral pathogens. An effective approach to identifying appropriate indicators may include the implementation of a battery of tests. The feasibility of using new methodologies such as monoclonal antibody and gene probe techniques should be compared to existing methods such as the fecal coliform Most Probable Number (MPN) to determine the most useful methods.

<u>2c. What human activities contribute most significantly to the numbers of human pathogens entering the marine environment?</u>

Discharges of raw sewage, dumping of sewage sludge, failing septic tanks, and wastewater effluent from sewage treatment plants represent the primary sources of some human pathogens to the marine environment (OTA, 1987). Pathogens may also enter the environment from nonpoint sources such as agricultural or stormwater runoff, or they may occur naturally in the marine environment. The illegal practice of ocean dumping of infectious wastes represents an episodic, but regionally significant, source of human pathogens in marine environments. The risk of exposure to these pathogens may be especially important in coastal areas near sites where hospital wastes have been illegally dumped. Efforts to classify shellfish-growing areas may be confounded by the presence of fecal wastes from domestic and wild, warm-blooded animals (e.g, cattle, dogs), which would be included in fecal coliform indicator measurements. Nonhuman fecal wastes, however, would not be expected to pose risks equivalent to that of human fecal wastes, because pathogens of concern, such as Norwalk-like and hepatitis A viruses, are not present in lower animal wastes.

NOAA researchers have examined the relative contribution of various point and nonpoint sources of marine pollution to the total pollution burden, and their effects on the quality of shellfish-growing waters in the Gulf of Mexico. NOAA-sponsored research is being conducted to determine the origin of fecal contamination found in the Mississippi Sound of the Gulf of Mexico. This work represents an initial effort to determine which human and nonhuman activities contribute most to the numbers of pathogens entering the marine environment. Also, by characterizing the relative contribution of point versus nonpoint sources of marine pollution, investigators could begin to determine if a relationship exists between manmade sources of pollution and the numbers of naturally occurring microorganisms in the marine environment.

The human activities that contribute most significantly to pathogens entering the marine environment have been identified. When needed for management purposes, region-specific studies may be necessary to determine the relative importance of local sources.

2d. Are present disinfection techniques adequate for controlling the introduction of pathogens into the marine environment?

Chlorination is the most commonly used disinfection technique in the United States (OTA, 1987). Traditionally viewed as an effective and economical mechanism to reduce the concentrations of pathogens in municipal effluents and sewage sludge, a growing body of evidence suggests that present methods and technologies vary in their effectiveness depending upon the particular type of pathogen. Conventional treatment processes (e.g., chlorination, thermal inactivation, anaerobic digestion, liming) can destroy some of the microorganisms present in municipal wastewaters (OTA, 1987). The effectiveness of the process depends on the techniques employed, the operating conditions, and the organism in question. Waterborne pathogens have a wide range of susceptibility to disinfection techniques. Miescier and Cabelli (1982) noted that viruses are relatively resistant to chlorination. Bacterial populations can be reduced about 15-fold through primary and secondary treatment and additional dilution can be achieved when the effluent is discharged into receiving waters. The degree of effectiveness of these processes against bacteria is generally high but they are not particularly effective against viruses and parasites such as protozoan cysts (Miescier and Cabelli, 1982; OTA, 1987).

Federal standards do not exist for disinfection procedures, such as disinfectant concentration and contact times. Consequently, these practices vary widely among different sewage treatment plants (Hoff and Akin, 1986). Although chlorination can be highly effective against bacteria (98%-99% destruction), other microorganisms such as viruses are more resistant and may survive treatment and eventually enter the marine environment. Higher disinfectant concentrations and longer contact times might be recommended against potentially resistant species. However, this practice raises the additional concern of increasing the levels of chlorinated byproducts in the environment. Of particular concern are low-molecular-weight halogenated hydrocarbons such as chloroform, bromodichloromethane, and dibromochloromethane. The extent and significance of occurrence of known and suspected carcinogens (e.g., trihalomethanes) was the principal objective of an early nationwide survey of organic chemicals in drinking water conducted by the Environmental Protection Agency (EPA, 1975). Additional research has focused on determining the mutagenicity, carcinogenicity, and target organ toxicity (renal, reproductive, and endocrine system) effects of disinfectants and disinfectant byproducts (NIEHS, 1986). However, a number of uncertainties exist with regard to the human health risk exposure to these compounds; therefore, research is still needed to determine the effects of disinfectants and disinfectant byproducts on human health.

A variety of disinfection treatment techniques have been proposed as alternatives to chlorination. These include use of ozone (ozonation), ultraviolet (uv) light, and gamma radiation treatment (OTA, 1987). Ozonation has been widely used in Europe to purify drinking water (Engineering News Record, 1985; SAIC, 1986) although it has been used infrequently in the United States for drinking water or municipal wastewater treatment. These techniques are difficult and expensive to apply, and therefore chlorination may be the only remaining practical means of disinfection in most locations.

Septic waste systems are commonly used for domestic sewage treatment in many coastal communities adjacent to shellfish-growing areas. These systems commonly fail, or are subject to improper or faulty operation owing to poor soil drainage characteristics, seasonally high water tables, or owner bypass/modifications. The degree of disinfection provided by such marginal systems should be evaluated as potential contributors to nonpoint source pollution in impacted shellfish-growing areas.

Alternative treatment systems and methods need to be developed that are highly effective against these pathogens where present treatment processes have a limited impact. Studies on the effectiveness and environmental implications of alternative treatment processes would be valuable, especially concerning the effectiveness against the release of hepatitis A and Norwalk viruses.

Effectiveness of Management Tools

Management Question 3: Have management tools been effective in protecting human health?

Information Needs

3a. Have public health advisories reduced risks associated with consumption of contaminated seafood?

3b. Have shellfish bed closures reduced consumption of contaminated shellfish?

3c. Have beach closures or restrictions prevented recreational exposure?

3a. Have public health advisories reduced risks associated with consumption of contaminated seafood?

The FDA has the lead responsibility for establishing and enforcing allowable levels of toxic substances in interstate commerce seafood under §408 and §409 of the Federal Food, Drug and Cosmetic Act (FFDCA). Section 406 of the FFDCA gives FDA the authority to set limits for chemical contaminants in fish and shellfish below which enforcement action will not be taken. These action and tolerance levels set by FDA for seafood are based on health risks associated with the average national seafood consumption estimates. The FDA has established action or tolerance levels for 11 organic contaminants and one metal. State and local environmental agencies and health departments are responsible for protecting consumers from the risks of consuming seafood products that are harvested locally. The public health advisory is one type of management tool available to regulators to warn the public of high levels of toxic substances in seafood. In many cases, state and local agencies rely on Federal guidelines concerning concentrations of contaminants that are considered unsafe for human consumption.

In an ongoing NOAA-sponsored study, public health advisories issued by the coastal and Great Lake states concerning the consumption of contaminated finfish have been surveyed; a nationwide database of advisory locations, fish species, and contaminants is being compiled; and state policies and public information regarding human health advisories are being analyzed. This information will be useful in analyzing the effectiveness of state and Federal programs in addressing health risks of consuming contaminated fish and identifying the fish species and contaminants that have been most closely linked with adverse health effects (Zeitlin, 1987).

The effectiveness of health advisories in altering public behavior is a potentially significant factor to be considered in establishing Federal action and tolerance levels. A limited number of studies have been conducted to determine the extent to which individual public health advisories influence fishing and seafood consumption behavior in the public. Belton and colleagues (1986), from the New Jersey Department of Environmental Protection, examined the effectiveness of public health advisories issued by the State of New Jersey in reducing the consumption of contaminated seafood. Surveys and interviews of urban fisherman revealed that many of them were not aware of the advisories, and that some had either misinterpreted the guidance or chosen to ignore it.

The public perception of risk and the ability of the regulatory agency to communicate that risk plays a large role in determining the effectiveness of the public health advisory. Jones et al. (1987) were able to characterize the comprehension of, and compliance with, a fish-consumption advisory aimed at reducing PCB intake by sport fishermen in Wisconsin. An initial survey of these fishermen conducted by questionnaire revealed that approximately three-fourths of the survey respondents were familiar with the fish consumption advisory, yet only 57% of the original respondents had changed their fishing or fish consumption habits as a result of the advisory.

Although the FDA has established limits for some of the important marine contaminants, many others remain unregulated. For example, regulatory limits have not been set for contaminants such as dioxin, polycyclic aromatic hydrocarbons, nonchlorinated pesticides, dibenzofurans, petroleum hydrocarbons, cadmium, lead, and arsenic. Based on the relative lack of action or tolerance levels for important seafood contaminants, it would be useful to establish safe limits for more of the potentially toxic and carcinogenic substances found in seafoods.

Although only a few studies have been conducted in this area, indications are that the issuance of advisories is only partially successful in influencing human behavior. However, the development of guidelines based on risk assessment and the issuing of health advisories is still considered the most effective means of getting people to reduce or cease consumption of contaminated seafood. Similar studies to those of Belton et al. (1986) and Jones et al. (1987) should be conducted in other sites around the country to make this management tool more effective in protecting human health.

3b. Have shellfish bed closures reduced consumption of contaminated shellfish?

Since 1966, data have been compiled periodically by FDA and NOAA on classifications by states of coastal and estuarine waters with regard to suitability for shellfishing activities. Individual state agencies classify shellfish-growing waters into the following categories: approved, conditionally approved, restricted, prohibited, or nonproductive. These designations are based primarily on the location of industrial and municipal waste discharges and measurements of indicators for the presence of pathogenic microorganisms in the water column. Data on shellfish area classifications are compiled in the National Shellfish Register of Classified Estuarine Waters (FDA and NOAA, 1985).

Public health management agencies at the state and local levels can take a direct role in limiting human exposure to contaminants in the marine environment by closing shellfish beds to harvesting. Enforcement of these actions is generally the responsibility of state and local law enforcement agencies. Signs and maps may be posted in the affected areas and legal notices can be published to alert persons harvesting shellfish or bathing in restricted areas (FDA and NOAA, 1985).

Although through the National Shellfish Sanitation Program serious enteric diseases such as hepatitis, cholera, and typhoid have been largely eliminated, it is still unclear whether closures are effective and efficient, especially for viral-induced types of gastroenteritis. Enforcement efforts are limited by manpower and budget considerations at the state level. More information would be needed to determine whether approved areas are safe, particularly in relation to the presence of free-living bacteria such as V. vulnificus, which may be unassociated with fecal contamination; and whether consumption of molluscan shellfish from restricted or prohibited areas results in a quantifiable risk to human health.

3c. Have beach closures or restrictions prevented recreational exposure?

One measure of the effectiveness of beach closures is the determination of disease incidence among bathers at restricted beaches. Beach closures are issued by state and local governments and are typically based on water quality criteria developed by the Federal Government. As indicated earlier, Cabelli et al. (1979) observed that symptom rates among swimmers at New York City beaches that were rated either "barely acceptable" or "relatively unpolluted" by a graduated pollution index were higher than those of nonswimmers at the same beaches.

It appears that classification of swimming beaches may not be totally effective in preventing the occurrence of swimming-related disease. Additional studies would need to be conducted at other sites to further characterize the effectiveness of beach closures based on Federal water quality criteria.

Concerns Associated with Spills of Hazardous Materials

Management Question 4: What are the human health concerns associated with spills of hazardous materials in the marine environment?

Information Needs

4a. What hazardous materials have been released into the marine environment as a result of accidental release/discharge?

4b. What health hazard(s) are encountered by workers involved in emergency response/cleanup actions?

4c. What are the health hazards to the general public as a result of exposures to toxic substances accidentally released into the marine environment?

Spills of hazardous or toxic materials into the marine environment may pose an immediate health risk to the general public as well as to workers involved in emergency response/cleanup efforts. Several Federal agencies are mandated to respond to incidents involving chemical discharges into the marine waters of the United States. The Coast Guard assumes primary Federal responsibility for the cleanup of hazardous materials spilled into the marine environment. To accomplish this mission, the Coast Guard has established a National Strike Force to respond to oil or chemical spills (Stull, 1987a). In addition to its actual response activities, the Coast Guard is also involved in the development and maintenance of information systems to document which hazardous materials have been released into inland or coastal waterways as a result of accidental discharges. The Pollution Incident Reporting System (PIRS) is a database of information on all spills of hazardous materials, oil, and other pollutants that have been reported to the Coast Guard since 1973. It contains information on dates, location, type, cause, source, and quantity of the spill, as well as the resources affected by the spill, the cleanup activities taken to mitigate the spill, and any penalty action taken against the polluter. This information is used for analysis and management purposes to allow the Coast Guard to identify those compounds that may represent the greatest hazard to the marine environment and to focus its response activities and R&D efforts on those compounds that are spilled most frequently. The PIRS is a dynamic system that is updated by approximately 1,000 records monthly.

The Coast Guard has also established the Chemical Hazard Response Information System (CHRIS), which provides a description of the hazards associated with over 1,000 chemicals and the appropriate response techniques for dealing with spills of these compounds. The CHRIS has four components: Condensed Guide to Chemical Hazards containing first aid information; Hazardous Chemical Data Manual describing the chemical, physical, and biological properties associated with each hazardous substance and measures to be taken in an emergency; Hazard Assessment Handbook, which is a series of formulas that simulate spill incidents; and the Response Methods Handbook containing techniques for cleaning up spills.

In addition to the development and maintenance of information systems, the Coast Guard has implemented an active program to develop and test chemical-protective clothing worn by personnel during chemical spill clean-up activities (Stull, 1987a; 1987b). Swope (1987) has prepared a summary of ongoing and planned Federal research on chemical-protective clothing and equipment performed or sponsored by the Coast Guard and other agencies such as NIOSH, OSHA, and EPA. *Research needs in this area currently include developing comprehensive performance standards for chemical-protective suits and designing even more chemically resistant suits (Stull, 1987a). Current efforts by the U.S. Coast Guard to address these needs should continue.*

Although the general public may also be at risk from exposure to accidental spills of hazardous materials in the marine environment, the risk is most often manifested through ingestion of contaminated seafood or direct exposure through swimming. These issues have been addressed in the previous management questions.

Conclusions and Recommendations

A number of toxic substances and human pathogens have been identified in the marine environment that have the potential to cause adverse human health effects. Although the presence of these agents in the marine environment does not alone constitute a public health risk, it does suggest that some potential health risk may be present if humans are exposed to these agents. The likelihood of developing adverse health effects from these substances is a result of the toxicity or pathogenicity of the agent and the extent to which the population is exposed.

The following conclusions concerning human health implications of marine pollution are based on the discussions of the management questions and information needs presented in the previous section.

- o Existing Federal and state monitoring programs provide limited data on the concentrations of chemical contaminants in edible tissues of commercial and recreational fish species. In addition, it is difficult to set "acceptable" limits for chemical concentrations in seafood because of uncertainties in our information on toxic response in humans, seafood consumption patterns in the United States, and exposure through other routes. Regulatory programs could be made more effective if these inadequacies were resolved.

- o Governmental programs, such as the National Shellfish Sanitation Program, have been largely effective in protecting the public from enteric diseases such as hepatitis, cholera, and typhoid, as well as from biotoxin poisoning associated with the consumption of molluscan shellfish. However, sporadic outbreaks of illness, primarily associated with free-living, opportunistic Vibrio species and gastroenteritis-causing viruses still occur.

- o Traditionally used microbial water quality indicators do not predict the occurrence of viral pathogens and naturally occurring pathogenic bacteria such as V. vulnificus.

- o Current information suggests that exposure to chemical pollutants during swimming and diving and through occupational activities related to seafood do not pose significant risks to human health in the United States at this time.

- o Current methods for the removal and inactivation of human pathogens are effective in controlling the input of enteric bacteria to the marine environment but not for other important pathogens such as the Norwalk-like viruses.

- o Seafood consumption advisories, shellfish bed closures, and beach classifications are issued by state and local governments using largely inconsistent methods and guidelines. Public responses to such advisories display wide differences in comprehension and compliance

Based on these conclusions, the following recommendations are made to improve our understanding of the implications of marine pollution to human health.

Chemical Contaminants

The following work would allow improved understanding of the human health concerns associated with exposure to chemical contaminants in the marine environment.

Concentrations in Commercial and Recreational Fisheries. More comprehensive information on concentrations of contaminants occurring in the major commercial and recreational species would improve our ability to manage public health risks. In addition to increasing temporal and geographical intensity of sampling, monitoring programs could be improved by establishing standard methods for sampling and analysis of seafood.

Seafood Consumption Patterns. Existing data on seafood consumption patterns do not adequately describe the dietary patterns of the relevant populations. Studies of seafood consumption patterns to update information and to focus on high-risk geographical or cultural populations would improve our ability to assess public health risks associated with consuming seafood.

Mixtures of Toxic Chemicals. It is difficult to predict the synergistic and antagonistic effects of most chemical mixtures. Although progress will be difficult, research should be continued in the following areas to increase the understanding of interactive effects of chemical mixtures on human health:

- Concentrations of toxic substances in mixtures;
- Toxicity to humans of individual contaminants; and
- The influence of environmental processes and interactions on toxic response.

Pathogens

The following work is needed to address the human health concerns associated with pathogenic microorganisms in the marine environment.

Microorganisms Causing Human Diseases. A number of sewage-associated pathogens in the marine environment are known or suspected to cause human diseases. Some pathogens are known to cause human disease but the link to the marine environment has not been established. Still other disease-causing microorganisms occur naturally in the marine environment or are introduced to seafood during improper handling, storage, or preparation. Research should continue to determine which marine pollution-related pathogens are causing human health effects. Efforts to improve our ability to monitor seafood and water quality for human pathogens should also continue.

Indicators. Traditionally used microbial water quality indicators do not predict the occurrence of viral pathogens and naturally occurring pathogenic bacteria such as *V. vulnificus*. Improved indicators need to be identified and validated on the basis of health risk data.

Sources. The major human activities that contribute human pathogens to the marine environment are known. Region-specific studies may be necessary to determine the relative importance of local sources.

Management Tools

The following work needs to be performed to determine the effectiveness of health advisories, shellfish bed closures, and beach closures in protecting human health.

Health Advisories. Current information indicates that health advisories are only partially effective in reducing the human health risk from consumption of contaminated seafood. However, this finding is based on relatively few studies. Studies similar to those of Belton et al. (1986) and Jones et al. (1987) conducted in other regions of the country would help to more accurately determine the effectiveness of health advisories.

Shellfish Bed Closures. Shellfish bed classification has been effective in protecting human health when NSSP microbiological standards and criteria for shellfish-growing areas have been used in proper context with other classification criteria (Hunt, 1979). Shellfish bed closures also have been effective with regard to marine biotoxins such as PSP and NSP. However, research would help to determine when approved shellfish areas are safe with respect to viruses and naturally occurring pathogens such as V. vulnificus.

Beach Closures. Additional studies are needed to assess the effectiveness of beach closures in protecting public health.

Hazardous Materials

The following work would help to determine the human health concerns associated with spills of hazardous materials in the marine environment.

Chemically Resistant Suits. Research needs include the development of comprehensive performance standards for chemical-protective suits worn by personnel during chemical spill clean-up activities, and the design of more chemically resistant suits. Current efforts by the U.S. Coast Guard to address these needs should continue.

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IV. PRIORITIES FOR ACTION

The purpose of this section is to present the National Ocean Pollution Policy Board's Agenda for Action during the interim between Plans. The action items are consistent with the needs and priorities identified in the discussions of individual goals. The action items listed are specific and implementable tasks so that, after some time has passed, we may determine whether the tasks have been accomplished.

Two categories of action items are listed below. The first category comprises a specific task, such as a study or report. The second involves the formation of an ad hoc working group or standing committee of agency specialists to develop a strategy for filling a specific need or to promote the startup and guide the conduct of multiple tasks. The Agenda for Action by the National Ocean Pollution Policy Board includes the following:

- Support Specific Tasks

  --Atmospheric Inputs of Toxic Substances
  --Future of Coastal Areas
  --Seafood Consumption Patterns
  --Indicators of the Presence of Human Pathogens

- Establish Ad Hoc Working Groups

  --Monitoring Environmental Quality of Marine Ecosystems
  --Habitat Loss and Modification
  --Biological Agents

Each of these tasks is described below.

SPECIFIC TASKS

Atmospheric Inputs of Toxic Substances. The Board will conduct and publish a state-of-the-art review concerning the sources, routes, and environmental significance of atmospheric inputs of selected toxic substances to the marine environment. The study will identify societal trends and technological developments that might influence future atmospheric inputs and assess the implications of these changes using a 25-year planning horizon. The report will also include a description of research needs and priorities for improved understanding of these issues. The study will be supported jointly by a group of interested Board agencies and directed by an ad hoc committee of Federal experts in this area.

<u>Future of Coastal Areas</u>. The Board will support a strategic assessment of future environmental problems in the Nation's coastal areas. The purpose of the study is to predict the most important environmental problems that will be faced by estuarine and coastal ecosystems over the next 50 years. The study will be conducted under the direction of a steering group of Federal, academic, industry, and environmental experts. The study will consider population growth and shifts to coastal areas, changes in industrial practices, future waste disposal requirements, economic development, technological improvements, and global changes in environmental quality and climate.

<u>Seafood Consumption Patterns</u>. The Board will support a study to update information on seafood consumption patterns in the United States and to identify population sectors (geographical, cultural, professional) at high risk from consumption of seafood contaminated with toxic substances. The study will evaluate the effectiveness of existing guidelines for limiting consumption of contaminated seafood in protecting high-risk sectors of the population. The study will also identify high-priority research needs related to this issue. The study will be conducted under the direction of the Board.

<u>Indicators of the Presence of Human Pathogens</u>. Estimates of the concentrations of fecal coliform bacteria have been traditionally used to indicate the presence of human pathogens in coastal waters. However, this indicator is not considered by many experts to be accurate, especially for health risks associated with viral diseases. The Board will support the development of improved indicators of human pathogens in the marine environment.

<u>AD HOC</u> WORKING GROUPS

<u>Monitoring Environmental Quality of Marine Ecosystems</u>. The Board will establish an <u>ad hoc</u> committee of Federal and private scientists and program managers to develop and examine the adequacy of information on the status of marine ecosystems. The committee will:

-- Establish the objectives of the Federal program in this area and determine appropriate roles at Federal and state levels of government.

-- Propose a systematic strategy for developing a national monitoring capability to meet these objectives. The strategy will incorporate existing national and regional programs, use of encountered data, peer review, and information synthesis and dissemination.

-- Promote the development of improved indicators of ecosystem status.

The committee will report to the Board and recommend actions to be taken by the Board.

<u>Habitat Loss and Modification</u>. Loss and modification of emergent vegetation and submerged aquatic vegetation is a major problem threatening the marine resources of the Nation. The Board will establish an <u>ad hoc</u> committee to promote the following:

-- Assure that National Wetlands Inventory (NWI) habitat maps in areas of rapid habitat loss are updated as frequently as necessary.

-- Evaluate the costs, benefits, and approaches for developing a high-resolution digital database for use in planning and documenting coastal alterations.

-- Assure that regional and national trends in habitat loss and modification are adequately documented.

-- Support research necessary to develop the capability to predict the effects of sea-level rise on coastal habitats.

-- Support a state-of-the-art review regarding the effectiveness of mitigation and restoration practices, particularly with regard to quality of habitat.

-- Prepare a program development plan for increasing our understanding of habitat functions and processes.

The committee will report to the Board on a regular basis regarding progress, problems, and needs for personnel, resources, or other types of assistance that might be required.

Biological Agents. The Board will conduct an evaluation of the Nation's ability to perform research on the effects of biological agents on marine organisms. The study will be supported by several Board agencies and directed by an ad hoc group of Federal and outside specialists. The purpose of the study is to:

-- Identify and assign priorities to research needs in this area.

-- Evaluate the adequacy of existing facilities to conduct secure (P3) biological research.

-- Assess capabilities for quick scientific response to investigate episodic events.

-- Evaluate the need for a common database to promote sharing of information on the occurrence and effects of biological agents.

-- Publish an annual review of the state-of-the-art and tally of the incidence of disease in marine biota.

The committee will report to the Board and recommend actions to be taken by the Board.

APPENDIX A: WORKING GROUP MEMBERS

During the development of this Federal Plan, six working groups were formed, and members were asked to provide guidance and information concerning the state-of-the-art, information needs, and research and monitoring recommendations pertaining to each of the six goal sections. The following list includes the names and affiliations of the members of each working group. The list also includes reviewers of the various goal sections who may not have been working group members. It should be noted that the discussions and recommendations presented in the goal sections may have been altered during official review by the National Ocean Pollution Policy Board. Therefore, it should not be assumed that this final version of the Plan necessarily reflects the consensus of the working groups. Staff members of the National Ocean Pollution Program Office (NOPPO) served as working group leaders and are listed with the respective groups.

Toxic Materials

Group Leader: W. Lawrence Pugh
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Joseph Bishop
NOAA, Estuarine Programs Office
Universal Bldg., South, Rm. 415
1825 Connecticut Ave., NW
Washington, DC 20235

Judy Capuzzo
Woods Hole Oceanographic Institution
Challenger Drive, Rm 213
Woods Hole, MA 02543

Jack Edmundson
U.S. Fish & Wildlife Service
Div. of Env. Contaminants
1000 N. Glebe Rd.
Arlington, VA 22201

John Farrington
University of Massachusetts at Boston
Harbor Campus
Morrissey Blvd.
Boston, MA 02125

Daniel Farrow
NOAA, Strategic Assessments Branch
Rockwall Bldg., Rm 666
11400 Rockville Pike
Rockville, MD 20852

Nick Fendinger
U.S. Dept. of Agriculture
Agriculture Research Service
Env. Chemical Lab.
Beltsville, MD 20705

Mary Gessner
NOAA, National Marine Fisheries Service
Universal Bldg., South, Rm 810
1825 Connecticut Ave., NW
Washington, DC 20235

Michael Harass
U.S. Food & Drug Administration
Env. Impact Section
200 C St., SW
Washington, DC 20204

Wayne Hollingsworth
U.S. Coast Guard Headquarters
Office of Marine Safety
2100 Second St., SW
Washington, DC 20593-001

George Hoskin
U.S. Food & Drug Administration
200 C St., SW
Washington, DC 20204

Clarence Johnson
U.S. Fish and Wildlife Service
Matomic Bldg., Rm 513
1717 H St., NW
Washington, DC 20240

Alex Lardis
U.S. Navy
David Taylor Research Center
Annapolis, MD 21402

Richard Latimer
U.S. Environmental Protection Agency
South Ferry Rd.
Narragansett, RI 02882

C.R. Lee
U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Mike Morrissette
U.S. Coast Guard Headquarters
Marine Technical & Hazardous Materials Div.
2100 Second St., SW
Washington, DC 20593-0001

Terri Paluszkiewicz
U.S. Dept. of the Interior
Minerals Management Service
Branch of Env. Modeling
18th and C Sts., NW
Washington, DC 20240

Albert Pohland
U.S. Food & Drug Administration
Div. of Contaminants Chemistry
200 C St., SW
Washington, DC 20204

John Pritchard
National Institute of Env. Health Sciences
Lab. of Pharmacology
Bldg. 19, Rm 1901B
Research Triangle Park, NC 27709

David Rathke
Great Lakes Regional Office
International Joint Commission
100 Ouellette Ave.
8th Floor
Windsor, Ontario N9A6T3

Aaron Rosenfield
National Oceanic and Atmospheric Administration
University of Maryland
Center for Env. and Estuarine Studies
P.O. Box 775
Cambridge, MD 21613

George Saunders
U.S. Dept. of Energy
Ecological Research Div.
ER-75, Rm E-239, Mail Stop E201
Washington, DC 20545

Carl Sinderman
NOAA, National Marine Fisheries Service
Cooperative Biological Lab
Oxford, MD 04270

John Stegeman
Woods Hole Oceanographic Institution
Challenger Drive
Woods Hole, MA 02543

Ben Thomas
Shell Development Company
P.O. Box 4320
Houston, TX 77210

John Trefrey
Dept. of Oceanography and Ocean Engineering
Florida Institute of Technology
Melbourne, FL 32901

Gordon Wallace
University of Massachusetts at Boston
Harbor Campus, Rm. 58
Morrissey Boulevard
Boston, MA 02125

Judith Weiss
Rutgers University
Dept. of Biological Sciences
Newark, NJ 07102

Nutrients

Group Leader: W. Lawrence Pugh
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Charles Alexander
NOAA, Strategic Assessments Branch
Rockwall Building, Rm 615
11400 Rockville Pike
Rockville, MD 20852

Rodger Baier
National Science Foundation
1800 G St., NW, Rm 611
Washington, DC 20550

Stan Chanesman
NOAA, National Marine Fisheries Service
Universal Bldg. South, Rm 810
1825 Connecticut Ave. NW
Washington, DC 20235

Chris D'Elia
Div. of Ocean Sciences
National Science Foundation
1800 G St., Rm 609
Washington, DC 20550

David Dolon
Great Lakes Regional Office
International Joint Commission
P.O. Box 32869
Detroit, MI 48232-2869

Thomas Fisher
Horn Point Lab.
University of Maryland
Cambridge, MD 21613

Art Hurme
U.S. Army Corps of Engineers, CECW-D
20 Massachusetts Ave., NW
Washington, DC 20314-1000

Gail Mackiernan
University of Maryland Sea Grant College
H.J. Patterson Hall, Rm 1224
College Park, MD 20742

Kent Mountford
U.S. Environmental Protection Agency
Chesapeake Bay Program
410 Severn Ave.
Annapolis, MD 21403

Hans Paerl
University of North Carolina-Chapel Hill
Institute of Marine Sciences
3407 Arendell St.
Morehead City, NC 28557

Jan Prager
U.S. Environmental Protection Agency
South Ferry Rd.
Narragansett, RI 02882

Kent S. Price
University of Delaware
College of Marine Studies
700 Pilottown Rd.
Lewes, DE 19958

John Pritchard
National Institute of Env. Health Sciences
P.O. Box 12233
Lab. of Pharmacology
Bldg. 19, Rm 1901B
Research Triangle Park, NC 27709

Berlie L. Schmidt
U.S. Dept. of Agriculture
Cooperative State Research Service/NRFSS
Justin Smith Morrill Bldg., Rm 121
15th St. & Independence Ave., SW
Washington, DC 20251

James Yoder
National Aeronautics & Space Administration
Oceanic Processes Branch (EEC)
Earth Science & Applications Div.
600 Independence Ave., SW
Rm 227B
Washington, DC 20546

Biological Agents

Group Leader: Laura Gabanski
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Jack Edmundson
U.S. Fish & Wildlife Service
Div. of Env. Contaminants
1000 N. Glebe Rd.
Arlington, VA 22201

Shay Fout
Div. of Microbiology
Center for Food Safety and Applied Nutrition
U.S. Food & Drug Administration
Mail Code HFF-235
200 C St., SW
Washington, DC 20204

Doug Gunnison
U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Sherwood Hall
U.S. Food & Drug Administration
Div. of Chemical Contaminants
Mail Code HFF-423
200 C St., SW
Washington, DC 20204

Fred Kern
NOAA, National Marine Fisheries Service
Cooperative Biological Lab.
Oxford, MD 04270

Morris Levin
U.S. Environmental Protection Agency
Office of Env. Processes and Effects Research
401 M St., SW, Rm. 682
Washington, DC 20460

Beth Milleman
Coastal Alliance
1536 16th St., NW
Washington, DC 20036

John Pritchard
National Institute of Env. Health Sciences
P.O. Box 12233
Lab. of Pharmacology
Bldg. 19, Rm 1901B
Research Triangle Park, NC 27709

Aaron Rosenfield
National Oceanic and Atmospheric Administration
University of Maryland
Center for Env. and Estuarine Studies
P.O. Box 775
Cambridge, MD 21613

Carl Sindermen
NOAA, National Marine Fisheries Service
Cooperative Biological Lab.
Oxford, MD 04270

Mark Sobsey
University of North Carolina at Chapel Hill
C.B. 7400, Rosenau Hall
Chapel Hill, NC 27559

Michael Stoskopf
National Aquarium
Pier 3
501 E. Pratt St.
Baltimore, MD 21202

Harris White
NOAA, Coastal and Estuarine Assessments Branch
Rockwall Bldg., Rm 645
11400 Rockville Pike
Rockville, MD 20852

Habitat

Group Leader: Laura Gabanski
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Donald Boesch
Louisiana Universities Marine Consortium
Chauvin, LA 70344

John Catena
The Oceanic Society
1536 Sixteenth St., NW
Washington, DC 20036

Charles Coutant
Env. Sciences Div.
Oak Ridge National Lab.
Oak Ridge, TN 37831-6038

John Day
Louisiana State University
Center for Wetland Resources
Coastal Ecology Institute
Baton Rouge, LA 70803

Jack Edmundson
U.S. Fish & Wildlife Service
Div. of Env. Contaminants
1000 N. Glebe Rd.
Arlington, VA 22201

Don Field
NOAA, Strategic Assessments Branch
Rockwall Bldg., Rm 661
11400 Rockville Pike
Rockville, MD 20852

Marion Fischel
Shell Oil Company
One Shell Plaza
P.O. Box 4320
Houston, TX 77210

Mary Gessner
NOAA, National Marine Fisheries Service
1825 Connecticut Ave., NW
Washington, DC 20235

Alex Lardis
U.S. Navy
David Taylor Research Center
Annapolis, MD 21402

Bill Sipple
U.S. Environmental Protection Agency
Office of Wetlands Protection
401 M St., SW
Washington, DC 20460

Nancy Sweeney
U.S. Fish and Wildlife Service
Div. of Endangered Species and Habitat Conservation
1000 N. Glebe Rd., Suite 500
Arlington, VA 22201

James Thomas
NOAA, National Marine Fisheries Service
Universal Bldg., South, Rm 810
1825 Connecticut Ave., NW
Washington, DC 20235

Larry Thomas
U.S. Fish and Wildlife Service
Div. of Endangered Species and Habitat Conservation
1000 N. Glebe Rd., Suite 500
Arlington, VA 22201

Robert Tucker
Assistant Director of Env. Research
New Jersey Dept. of Env. Protection
Trenton, NJ 08625

Gerald Welsh
U.S. Dept. of Agriculture
Soil Conservation Service SES/ECS
South Bldg., Rm 6142
12th and Independence Ave., SW
Washington, DC 20013

Bill Wilen
U.S. Fish & Wildlife Service
National Wetlands Inventory
1000 N. Glebe Rd., Rm 500
Arlington, VA 22201

Douglas Wolfe
NOAA, Ocean Assessments Div.
Rockwall Bldg., Rm 656
11400 Rockville Pike
Rockville, MD 20852

Tom Wright
U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. 631
Vicksburg, MS 39180-0631

Ecosystem Status

Group Leaders: Sari Kiraly
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

William G. Conner
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Neal Armstrong
Dept. of Civil Engineering
The University of Texas
Austin, TX 78712

Fred Calder
Coastal Zone Management Section
Florida Dept. of Env. Regulation
2600 Blair Stone Rd.
Tallahassee, FL 32301-8241

James R. Chambers
NOAA, Office of Resource Investigations
Universal Bldg., Rm 810
1825 Connecticut Ave., NW
Washington, DC 20235

Celia Chen
Marine Board
National Academy of Sciences
2101 Constitution Ave.
Washington, DC 20418

Jack Edmundson
U.S. Fish and Wildlife Service
Div. of Env. Contaminants
1000 N. Glebe Rd.
Arlington, VA 22201

Dave Farrell
U.S. Dept. of Agriculture
Bldg., 005, Rm 201
BARC - West
Beltsville, MD 20705

Mark Harwell
Ecosystems Research Center
Hollister Hall
Cornell University
Ithaca, NY 14853

Art Hurme
U.S. Army Corps of Engineers, CECW-D
20 Massachusetts Ave., NW
Washington, DC 20314-1000

Jack Kelly
Ecosystems Research Center
Corson Hall
Cornell University
Ithaca, NY 14853

Gerd Kleineberg
U.S. Coast Guard
Chief, Chemistry Branch
Research and Development Center
Avery Point
Croton, CT 06340-6096

Jay Means
Institute for Env. Studies
42 Atkinson Hall
Louisiana State University
Baton Rouge, LA 70803

Bob Middleton
DOI, Minerals Management Service
12203 Sunrise Valley Drive
MS 644
Reston, VA 22091

Joel O'Conner
U.S. Environmental Protection Agency
26 Federal Plaza, Rm 805
New York, NY 1007-0090

Don Phelps
U.S. Environmental Protection Agency
South Ferry Rd
Narragansett, RI 02882

Andy Robertson
NOAA, Ocean Assessments Div.
Rockwall Bldg., Rm 652
11400 Rockville Pike
Rockville, MD 20852

George Sanders
U.S. Dept. of Energy
ER-75, Rm E-239
Mail Stop E201
Washington, DC 20545

Doug Segar
Senior Research Scientist
Tiburon Center for Env. Studies
7609 Potrero Ave.
El Cerrito, CA 94530

Bob Zeller
U.S. Environmental Protection Agency
Office of Marine & Estuarine Protection
401 M St., SW
Washington, DC 20460

Human Health

Group Leaders: Devorah Zeitlin
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Edward Flynn
NOAA, National Ocean Pollution Program Office
Rockwall Bldg., Rm 610
11400 Rockville Pike
Rockville, MD 20852

Victor Cabelli
University of Rhode Island
Dept. of Microbiology
Kingston, RI 02881

Rita Colwell
University of Maryland
Dept. of Microbiology
College Park, MD 20742

Clyde Dawe
Woods Hole Oceanographic Institution
59 School St.
Woods Hole, MA 02543

Tom Dillon
U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Fred Felleman
Center for Env. Education
1725 DeSales St., NW
Suite 500
Washington, DC 20036

James Fouts
National Institute of Env. Health Sciences
Mail Drop A-203
P.O. Box 12233
111 Alexander Drive
Research Triangle Park, NC 27709

Mary Jo Garreis
Maryland Dept. of the Env.
Div. of Standards & Certification
P.O. Box 13387
201 West Preston Street
Baltimore, MD 21201

E. Spencer Garrett
NOAA, National Marine Fisheries Service
P.O. Drawer 1207
Pascagoula, MS 39568-1207

Betty Hackley
NOAA, National Marine Fisheries Service
Universal Bldg., Rm 814
1825 Connecticut Ave., NW
Washington, DC 20235

Clarence Johnson
U.S. Fish and Wildlife Service
Region 8 Office of Research Support
Matomic Bldg., Rm 527
18th and C Sts., NW
Washington, DC 20240

Howard Kator
Virginia Institute of Marine Science
Gloucester Point, VA 23062

David Kleffman
U.S. Environmental Protection Agency
Health Research, RD-683
401 M St., SW
Washington, DC 20460

Ronald Landy
U.S. Food and Drug Administration
Center for Veterinary Medicine
HFV 222, Rm 7B45
5600 Fishers Lane
Rockville, MD 20857

Dorothy Leonard
NOAA, Strategic Assessments Branch
Rockwall Bldg., Rm 600
11400 Rockville Pike
Rockville, MD 20852

Trent Lewis
U.S. Environmental Protection Agency
Div. of Toxicology and Microbiology
26 W. Martin Luther King Drive
Cincinnati, OH 45268

Eric May
NOAA, National Marine Fisheries Service
South Morris Street Extension
Oxford, MD 21654

James McKinney
National Institutes of Health
National Institute of Env. Health Sciences
P.O. Box 12233
Research Triangle Park, NC 27711

Malcolm Meaburn
NOAA, National Marine Fisheries Service
P.O. Box 12607
Charleston, SC 29412

Bill Morgan
W.F. Morgan & Sons, Inc.
Box 241, Route 632
Weems, VA 22576

Joel O'Conner
U.S. Environmental Protection Agency
26 Federal Plaza, Rm 805
New York, NY 10007-0090

Vincent Olivieri
John Hopkins University
Dept. of Geography & Env. Engineering
G.W.C. Whiting School of Engineering
109 Ames Hall
Baltimore, MD 21218

Robert Scheuplein
U.S. Food and Drug Administration
Office of Toxicological Sciences, HFF-101
Center for Food Safety for Applied Nutrition
200 C St., SW, Rm 5022
Washington, DC 20204

Will Stelle
Counsel, House Merchant Marine & Fisheries Committee
Fish and Wildlife Subcommittee
House Office Bldg., Annex II, Rm 543
Washington, DC 20515

Richard Thompson
Division of Shellfish Sanitation Control
Texas State Dept. of Health
1100 W. 49th St.
Austin, TX 78754

Harris H. White
NOAA, Ocean Assessments Div.
Rockwall Bldg., Rm 645
11400 Rockville Pike
Rockville, MD 20852

APPENDIX B: THE NATIONAL OCEAN POLLUTION PLANNING ACT (Public Law 95-273)

CHAPTER 31—OCEAN POLLUTION RESEARCH AND DEVELOPMENT AND MONITORING PLANNING

Related Provisions

See, also, Water Pollution Prevention and Control, 33 U.S.C.A. § 1251 et seq., ante; Ocean Dumping, 33 U.S.C.A. § 1401 et seq., ante; Prevention of Pollution from Ships, 33 U.S.C.A. § 1901 et seq., post; and Water Resources Research, 42 U.S.C.A. § 10301 et seq., post.

Library References

Health and Environment ⇐25.7(3).
C.J.S. Health and Environment § 106.

WESTLAW Electronic Research

See WESTLAW guide following the Explanation pages of this pamphlet.

§ 1701. Findings and purposes [NOPPA § 2]

(a) The Congress finds and declares the following:

(1) Man's activities in the marine environment can have a profound short-term and long-term impact on such environment and greatly affect ocean and coastal resources therein.

(2) There is a need to establish a comprehensive Federal plan for ocean pollution research and development and monitoring, with particular attention being given to the inputs, fates, and effects of pollutants in the marine environment.

(3) Man will increasingly be forced to rely on ocean and coastal resources as other resources are depleted. Our ability to protect, preserve, develop, and utilize these ocean and coastal resources is directly related to our understanding of the effects which ocean pollution has upon such resources.

(4) Numerous departments, agencies, and instrumentalities of the Federal Government sponsor, support, or fund activities relating to ocean pollution research and development and monitoring. However, such activities are often uncoordinated and can result in unnecessary duplication.

(5) Better planning and more effective use of available funds, personnel, vessels, facilities, and equipment is the key to effective Federal action regarding ocean pollution research and development and monitoring.

(6) Numerous Federal agencies have initiated and supported research projects to study, enhance,

manage, preserve, protect, or restore the resources of the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance.

(7) Various research projects relating to the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance, including those conducted at the college and university level and those conducted at the State and local governmental level, can be more effectively coordinated in order to obtain maximum benefits.

(b) It is therefore the purpose of the Congress in this chapter—

(1) to establish a comprehensive 5-year plan for Federal ocean pollution research and development and monitoring programs in order to provide planning for, coordination of, and dissemination of information with respect to such programs within the Federal Government;

(2) to develop the necessary base of information to support, and to provide for, the rational, efficient, and equitable utilization, conservation, and development of ocean and coastal resources;

(3) to provide for the effective coordination of research conducted to support the preservation and protection of the environmental quality of the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance, and to encourage the use of such research in determinations that affect the environmental quality of the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance; and

(4) to designate the National Oceanic and Atmospheric Administration as the lead Federal agency for preparing the plan referred to in paragraph (1) and to require the Administration to carry out a comprehensive program of ocean pollution research and development and monitoring under the plan.

(May 8, 1978, Pub.L. 95-273, § 2, 92 Stat. 228; April 7, 1986, Pub.L. 99-272, Title VI, § 6071, 100 Stat. 133.)

Short Title

Section 1 of Pub.L. 95-273, May 8, 1978, 92 Stat. 228, as amended Pub.L. 96-255, § 3, May 30, 1980, 94 Stat. 420, provided: "That this Act [enacting this chapter] may be cited as the 'National Ocean Pollution Planning Act of 1978'."

§ 1702. Definitions [NOPPA § 3]

As used in this chapter, unless the context otherwise requires—

(1) The term "Administration" means the National Oceanic and Atmospheric Administration.

(2) The term "Administrator" means the Administrator of the Administration.

(3) The term "Board" means the National Ocean Pollution Policy Board established under section 1702a(b) of this title.

(4) The term "Director" means the Director of the Office of Science and Technology Policy in the Executive Office of the President.

(5) The term "marine environment" means the coastal zone (as defined in section 1453(1) of title 16); the seabed, subsoil, and waters of the territorial sea of the United States; the waters of any zone over which the United States asserts exclusive fishery management authority; the waters of the high seas; and the seabed and subsoil of and beyond the Outer Continental Shelf.

(6) The term "ocean and coastal resource" has the same meaning as is given such term in section 1122(7) of this title.

(7) The term "ocean pollution" means any short-term or long-term change in the marine environment.

(8) The term "Office" means the National Ocean Pollution Program Office established under section 1702a(a) of this title.

(May 8, 1978, Pub.L. 95-273, § 3, 92 Stat. 228; April 7, 1986, Pub.L. 99-272, Title VI, § 6072(1), 100 Stat. 133.)

§ 1702a. National Ocean Pollution Program Office and Policy Board [NOPPA § 3A]

(a) Program Office

(1) The Administrator shall establish within the Administration the National Ocean Pollution Program Office.

(2) The Office shall—

(A) serve as the lead entity responsible for administering the program established under section 1703 of this title;

(B) be headed by a director who shall—

(i) be appointed by the Administrator,

(ii) serve as the Chair of the Board, and

(iii) be the spokesperson for the program;

(C) serve as the staff for the Board and its supporting committees and working groups; and

(D) review each department and agency budget request transmitted under section 1703(d) of this title and submit an analysis of the requests to the Board for its review.

The analysis described in subparagraph (D) shall include an analysis of how each departmental or agency budget request relates to the priorities and goals of the Plan established under section 1703 of this title.

(b) Policy Board

(1) The Administrator, with the cooperation of the Federal departments and agencies referred to in section 1706 of this title, shall establish a National Ocean Pollution Policy Board consisting of representatives of those departments and agencies.

(2) The Board shall—

(A) be responsible for coordinated planning and progress review for the program established under section 1703 of this title;

(B) review all department and agency budget requests transmitted to it under section 1703(d) of this title and submit a report to the Office of Management and Budget and to the Congress concerning those budget requests;

(C) establish and maintain such interagency groups as the Board determines to be necessary to carry out its activities; and

(D) consult with and seek the advice of users and producers of ocean pollution data, information, and services to guide the Board's efforts, keeping the Director and the Congress advised of such consultations.

(Pub.L. 95–273, § 3A, as added April 7, 1986, Pub.L. 99–272, Title VI, § 6072(2), 100 Stat. 133.)

§ 1703. Comprehensive Federal Plan relating to ocean pollution [NOPPA § 4]

(a) Lead agency for Plan

The Administrator, in consultation with the Director and other appropriate Federal officials having authority over ocean pollution research and development and monitoring programs, shall prepare, in accordance with this section, a comprehensive 5-year plan (hereinafter in this chapter referred to as the "Plan") for the overall Federal effort in ocean pollution research and development and monitoring. The Plan shall be prepared and submitted to Congress and the President on or before February 15, 1979, and a revision of the plan shall be prepared and so submitted by September 15 every three years after 1979.

(b) Content of Plan

The Plan shall contain, but need not be limited to, the following elements:

(1) Assessment and ordering of national needs and problems

The Plan shall—

(A) identify those national needs and problems, which relate to specific aspects of ocean pollution (including, but not limited to, the effects of ocean pollution on the economic, social, and environmental values of ocean and coastal resources), which exist and will arise during the Plan period;

(B) establish the priority, based upon the value and cost of information which can be obtained from specific ocean pollution research and development and monitoring programs and projects, in which such needs should be met, and such problems should be solved, during the Plan period; and

(C) contain, if pursuant to the preparation of any revision of the Plan required under subsection (a) of this section it is determined that any national need or problem or priority set forth in the preceding version of the Plan should be changed, a detailed explanation of the reasons for the change.

(2) Existing Federal capability

The Plan shall contain—

(A) a detailed listing of all existing Federal programs relating to ocean pollution research and development and monitoring (including, but not limited to, general research on marine ecosystems, including the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance,) which listing shall include, with respect to each such program—

(i) a catalogue of the Federal personnel, facilities, vessels and other equipment currently assigned to, or used for, the program, and

(ii) a detailed description of the existing goals and costs of the program, including, but not limited to, a categorical breakdown of the funds currently being expended, and planned to be expended, to conduct the program; and

(B) an analysis of the extent to which each such program, if continued on the basis and at the funding level described pursuant to subparagraph (A)(ii), will assist in meeting the priorities set forth pursuant to paragraph (1)(B) during the Plan period.

(3) **Policy recommendations**

If it is determined, as a result of the analysis required to be made under paragraph (2)(B), that the priorities set forth pursuant to paragraph (1)(B) will not be adequately met during the Plan period using the existing Federal capability described pursuant to paragraph (2)(A), the Plan shall contain those recommendations for changes in the overall Federal effort in ocean pollution research and development and monitoring which would ensure that those priorities are adequately met during the Plan period. Such recommendations may include, but need not be limited to—

(A) changes in the goals to be achieved under various existing Federal ocean pollution research and development and monitoring programs;

(B) suggested increases and decreases in the funding for any such existing program consistent with the extent to which such program contributes to the meeting of such priorities;

(C) specific proposals for interagency cooperation in cases in which the pooling of the resources of two or more Federal departments, agencies, or instrumentalities under existing programs could further efforts to meet such priorities or would eliminate duplication of effort; and

(D) suggested legislation to establish new Federal programs considered to be necessary if such priorities are to be met.

(4) **Plan review**

The Plan shall contain a description of actions taken by the Administrator and the Director for the purpose of ensuring interagency coordination and cooperation in (A) the carrying out of Federal ocean pollution research and development and monitoring programs; and (B) eliminating unnecessary duplication of effort among such programs.

(c) **Plan period**

For purposes of this section, the term "Plan period" means—

(1) with respect to the Plan as required to be submitted on February 15, 1979, the period of 5 fiscal years beginning on October 1, 1978; and

(2) with respect to each revision of the Plan, the period of 5 fiscal years beginning on October 1 of the year before the year in which the revision is required to be prepared under subsection (a) of this section.

(d) **Budgeting**

Each Federal agency and department included under the Plan shall prepare and submit to the Office of Management and Budget, the Office, and the Board on or before the date of submission of departmental requests for appropriations to the Office of Management and Budget, an annual request for appropriations to carry out the activities of that agency or department under the Plan during the subsequent fiscal year. The Office of Management and Budget shall review the request for appropriations as an integrated, coherent, and multiagency request, taking into account the review by the Board of those requests under section 1702a(b) of this title.

(May 8, 1978, Pub.L. 95–273, § 4, 92 Stat. 229; May 30, 1980, Pub.L. 96–255, § 2, 94 Stat. 420; Dec. 21, 1982, Pub.L. 97–375, Title II, § 202(c), 96 Stat. 1822; April 7, 1986, Pub.L. 99–272, Title VI, § 6073, 100 Stat. 134.)

Cross References

Comprehensive ocean pollution program, content of, see section 1704 of this title.

Grants and contracts for research, development, and monitoring projects or activities, see section 1705 of this title.

§ 1704. Comprehensive ocean pollution program in the Administration [NOPPA § 5]

(a) **Establishment of program**

The Administrator shall establish within the Administration a comprehensive, coordinated, and effective ocean pollution research and development and monitoring program. The Administrator shall carry out all projects and activities under the program in a manner consistent with the Plan.

(b) **Content of the program**

The program required to be established under subsection (a) of this section shall include, but not be limited to—

(1) all projects and activities relating to ocean pollution research and development and monitoring for which the Administrator has responsibility under provisions of law (including, but not limited to, title II of the Marine Protection, Research, and Sanctuaries Act of 1972 (33 U.S.C. 1441–1444)) other than paragraph (2);

(2) such projects and activities addressed to the priorities set forth in the Plan pursuant to section 1703(b)(1)(B) of this title that can be appropriately conducted within the Administration; and

(3) the provision of financial assistance under section 1705 of this title.

(May 8, 1978, Pub.L. 95–273, § 5, 92 Stat. 230.)

§ 1705. Financial assistance [NOPPA § 6]

(a) Grants and contracts

The Administrator may provide financial assistance in the form of grants or contracts for research and development and monitoring projects or activities which are needed to meet priorities set forth in the Plan pursuant to section 1703(b)(1)(B) of this title, if such priorities are not being adequately addressed by any Federal department, agency, or instrumentality.

(b) Applications for assistance

Any person, including institutions of higher education and departments, agencies, and instrumentalities of the Federal Government or of any State or political subdivision thereof, may apply for financial assistance under this section for the conduct of projects and activities described in subsection (a) of this section, and, in addition, specific proposals may be invited. Each application for financial assistance shall be made in writing in such form and manner, and contain such information, as the Administrator may require. The Administrator may enter into contracts under this section without regard to section 5 of title 41.

(c) Existing programs

The projects and activities supported by grants or contracts made or entered into under this section shall, to the maximum extent practicable, be administered through existing Federal programs (including, but not limited to, the National Sea Grant Program) concerned with ocean pollution research and development and monitoring.

(d) Action by Administrator

The Administrator shall act upon each application for a grant or contract under this section within six months after the date on which all required information is received by the Administrator from the applicant. Each grant made or contract entered into under this section shall be subject to such terms and conditions as the Secretary deems necessary in order to protect the interests of the United States. The total amount paid pursuant to any such grant or contract may, in the discretion of the Administrator, be up to 100 percent of the total cost of the project or activity involved.

(e) Records

Each recipient of financial assistance under this section shall keep such records as the Administrator shall prescribe, including records which fully disclose the amount and disposition by such recipient of the proceeds of such assistance, the total cost of the project or activity in connection with which such assistance was given or used, the amount of that portion of the cost of the project or activity which was supplied by other sources, and such other records as will facilitate an effective audit. Such records shall be maintained for three years after the completion of such project or activity. The Administrator and the Comptroller General of the United States, or any of their duly authorized representatives, shall have access, for the purpose of audit and examination, to any books, documents, papers, and records of receipts which, in the opinion of the Administrator or of the Comptroller General, may be related or pertinent to such financial assistance.

(May 8, 1978, Pub.L. 95–273, § 6, 92 Stat. 231.)

Cross References

Comprehensive ocean pollution program, content of, see section 1704 of this title.

§ 1706. Interagency cooperation [NOPPA § 7]

The head of each department, agency, or other instrumentality of the Federal Government which is engaged in or concerned with, or which has authority over, programs relating to ocean pollution research and development and monitoring—

(1) shall cooperate with the Administrator in carrying out the purposes of this chapter;

(2) may, upon written request from the Administrator or Director, make available to the Administrator or Director, on a reimbursable basis or otherwise, such personnel (with their consent and without prejudice to their position and rating), services, or facilities as may be necessary to assist the Administrator or the Director to achieve the purposes of this chapter; and

(3) shall, upon a written request from the Administrator or Director, furnish such data or other information as the Administrator or Director deems necessary to fulfill the purposes of this chapter.

(May 8, 1978, Pub.L. 95–273, § 7, 92 Stat. 232.)

§ 1707. Dissemination of information on ocean and Great Lakes pollution research activities [NOPPA § 8]

(a) The Administrator shall ensure that the results, findings, and information regarding ocean pollution research and development and monitoring programs conducted or sponsored by the Federal Government be disseminated in a timely manner, and in useful forms, to relevant departments, agencies, and instrumentalities of the Federal Government, and to other persons having an interest in ocean pollution research and development and monitoring.

(b) The Administrator shall ensure that the findings and information regarding ocean pollution research activities associated with the Great Lakes identified pursuant to section 1703(b) of this title be disseminated in a timely manner and in useful forms to relevant departments of the Federal Government, State governments, and other persons with an interest in such information.

(May 8, 1978, Pub.L. 95–273, § 8, 92 Stat. 232; April 7, 1986, Pub.L. 99–272, Title VI, § 6074, 100 Stat. 135.)

§ 1708. Effect on other laws [NOPPA § 9]

Nothing in this chapter shall be construed to amend, restrict, or otherwise alter the authority of any Federal department, agency, or instrumentality, under any law, to undertake research and development and monitoring relating to ocean pollution.

(May 8, 1978, Pub.L. 95–273, § 9, 92 Stat. 232.)

§ 1709. Authorization of appropriations [NOPPA § 10]

There are authorized to be appropriated to the Administration for the purposes of carrying out this chapter not to exceed $5,000,000 for the fiscal year ending September 30, 1979, not to exceed $4,300,000 for the fiscal year ending September 30, 1980, not to exceed $3,000,000 for the fiscal year ending September 30, 1981, not to exceed $4,000,000 for the fiscal year ending September 30, 1982, and not to exceed $3,571,000 for fiscal year 1986, and not to exceed $3,732,000 for fiscal year 1987.

(May 8, 1978, Pub.L. 95–273, § 10, 92 Stat. 232; June 4, 1979, Pub.L. 96–17, 93 Stat. 34; May 30, 1980, Pub.L. 96–255, § 1, 94 Stat. 420; April 7, 1986, Pub.L. 99–272, Title VI, § 6075, 99 Stat. 135.)

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